THE

JOURNAL OF GEOLOGY

NOVEMBER–DECEMBER, 1910

A CENTRAL AFRICAN GLACIER OF TRIASSIC AGE[1]

SYDNEY H. BALL AND MILLARD K. SHALER
New York City, N.Y.

INTRODUCTION

From June, 1907, to June, 1909, the writers directed the prospecting work of the Société Internationale Forestière et Minière du Congo in the Belgian Congo, more familiarly known by its former name, the Congo Free State (Fig. 1). In the zone of the Maniema (Fig. 2), in the eastern part of the colony, evidences of glacial action of Jura-Triassic age were noted, which seem worthy of description.

The data of a scientific nature were collected during the two years passed in the Belgian Congo, incidental to an economic reconnaissance of the country, and is consequently of a fragmentary character. Difficulties of work in a partially explored tropical country also explain the lack of detail in this paper. Topography by R. B. Oliver is the base used, and field notes by A. E. Smith are drawn upon in the preparation of this paper.

LOCATION AND AREA

Belgian Congo lies in southwestern Central Africa to the west of the Continental Divide. It has a coast line of but twenty miles on the Atlantic, but widens rapidly eastward to points 5 degrees north and 14 degrees south of the equator. Its area is 908,000

[1] Published by permission of the Société Internationale Forestière et Minière du Congo.

square miles, or greater than that of all the United States east of the Mississippi River.

The zone of the Maniema is situated in the Upper Congo region, and includes that part of the Lualaba (Congo) Valley between latitudes 3 and 5 degrees south. The principal state post in the zone is Kasongo (Fig. 1).

TOPOGRAPHY AND DRAINAGE

From north to south, Africa is made up of three topographic elements: the Atlas Mountains, a highly accentuated region of closely folded rock; the Soudan and Sahara desert region, a more or less accidented plain in which the rocks are, in the main, flat-lying; and the central and southern tablelands with the Abyssinian plateau, consisting of intensely folded older, and horizontal younger rocks.

The Belgian Congo lies within the plateau region, and consists from west to east of: (1) a narrow coastal plain, which faces the Atlantic Ocean, rising to (2) an ancient mountain range, now eroded to an intensely dissected plateau, and frequently referred to as the Crystal Mountains (the higher domes reach an altitude of 2,300 feet; through the hard rocks of this plateau the mighty Congo rushes in a series of rapids, and low waterfalls, the non-navigable stretch between the Lower and Upper Congo rivers); (3) the great interior region, a basin whose slopes rise gently from Lake Leopold II (altitude 1,110 feet). The limits of the basin to the north (altitudes from 2,500 to 4,200 feet) and to the south (from 4,000 to 5,000 feet) are comparatively low, but to the east rise the Eastern Frontier Mountains, in height averaging about one mile above sea-level. Certain peaks like the volcanic Ruwenzori (altitude 16,800 feet) rise to altitudes exceeding 15,000. These mountains are in part due to folding, but largely to north-and-south faulting with which are genetically connected important volcanic phenomena.

The Congo River and its tributaries drain the Belgian Congo with the exception of a small area in the extreme northeastern part, the waters of which find their way into the Nile. The principal affluents of the Congo are the Kasai, Sankuru, and Ubangi. It is 4,640 kilometers in length, and the sixth longest river in the world.

GENERAL GEOLOGY (Fig. 1)

The coastal plain is underlain by marine sandstones which are inclined gently toward the ocean. The sandstones, which are covered by recent alluvium at the Congo mouth, are considered by geologists who are familiar with them to be of Tertiary and Cretaceous age.

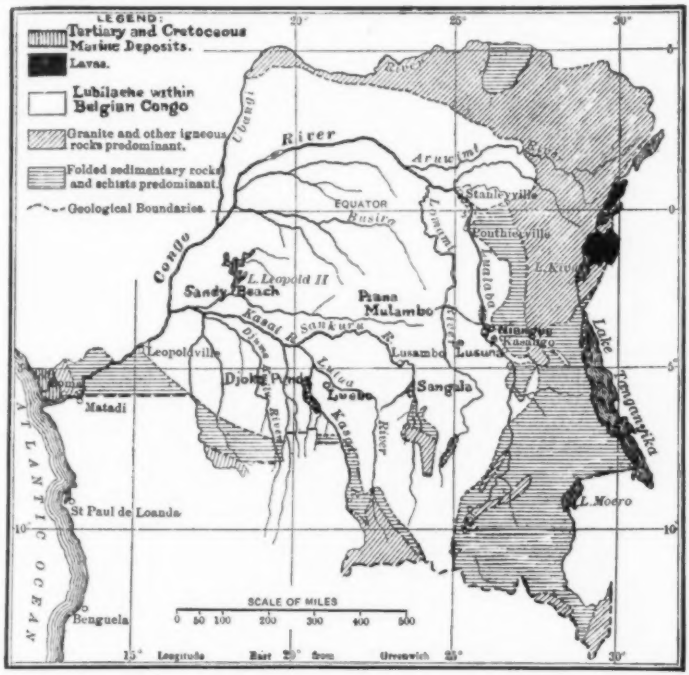


FIG. 1.—Showing approximate geological boundaries in the Belgian Congo

The so-called Crystal Mountains consist of older rocks, the age of which has not yet been satisfactorily determined. The older members of the series consist of mica schists and sericitic quartzites, interbedded with which are chlorite and epidote schists, representing either basic lavas contemporaneous with the sedimentary rocks, or very ancient intrusive bodies of igneous rocks.

Of later origin are intrusive masses of granite and gabbro, now

mashed and recrystallized into gneisses. Large bodies of granite and smaller ones of diabase also occur.

To the east of these older rocks are limestones and calcareous schists, which near the ancient complex are closely folded, but are flat-lying farther east, half-way between Matadi and Leopoldville. These beds are considered by E. Dupont[1] to be of Devonian age. To the east they are unconformably overlain by red sandstones and shales, the Kundulungu (Permo-Carboniferous) of Professor Jules Cornet.[2]

The great interior region is covered by the Lubilache formation, a series of interbedded sandstones and shales, either flat-lying or dipping gently toward the center of the basin. The formation, the lower surface of which is undulating, thins rapidly on the upper slopes of the basin. As the rim of the basin is approached, isolated inliers of older folded and faulted rocks begin to appear where valleys cut through the sandstone-shale blanket, and encounter low domes on the old surface.

These older rocks are similar, in a general way, to those of the Crystal Mountains. They consist of very ancient mica schists, quartzites, and igneous schists and gneisses, which are cut by gabbros and granites. Younger than the granites are folded sandstones, quartzites, slates, shales, and limestones. Cornet is, without much question, correct in his belief that these two series of rocks are respectively of pre-Cambrian and Paleozoic age, although, unfortunately fossils have nowhere been found in them. In the Eastern Mountain area are also modern and Tertiary lavas.

The main structural features on the north and south rims of the Congo basin have an east-and-west trend, while the rocks of the Eastern Mountains strike north-and-south. The position of Lakes Tanganyika, Kivu, Albert Edward, and Albert and of the mountain ranges near by has been determined largely by faults, the trends of which are approximately parallel to the strike of the rocks.

[1] *Lettres sur le Congo* (1889), Paris.

[2] *Bulletin Société Géologique de Belgique*, XXI, 262.

LUBILACHE FORMATION

The Lubilache formation, in which the glacial features occur, was first described by Dupont[1] and named by Cornet[2] from the Lubilache (Sankuru) River, where it is typically developed. It is the essentially flat-lying sandstone-shale series which covers the central Congo basin, not rarely extends in tongues into the rim plateau and mountain regions, and at several points crosses beyond the Congo basin. In general this series is made up of sandstones and shales in alternating beds, which grade into one another both laterally and vertically.

As a rule massive bedding predominates in the sandstones as does a reddish color; grayish and white beds are, however, not uncommon.

In the lower Kasai region particularly, a quartzitic phase is often developed in the sandstones by the deposition of secondary silica by surface waters. In extreme instances this action results in a rock almost cherty in character, which is often cellular, the weathered surface being pitted. In the upper Kasai and Sankuru regions this quartzitic phase is rare, the sandstones being medium grained and having usually a saccharoidal texture. In the Lualaba (Upper Congo) area hard, fine-grained maroon sandstones cemented with a ferruginous pigment predominate. In all cases the sandstones are typically quartzose, although near the base of the formation at many places, feldspathic material is present.

The shales are usually fissile and vary in color from greenish gray to tan and drab.

In the vicinity of Nyangwe, on the Lualaba River (Upper Congo), shales, well exposed, are more or less bituminous, but grade laterally both up and down the river into more arenaceous beds. West of Kasongo, toward Lusunu, these beds are almost sandstones.

The basal beds of the formation are generally slightly conglomeratic. In the vicinity of the junction of the Lulua and Kasai rivers the ancient erosional surface upon which the flat-lying sandstones and shales were deposited undulated very gently. The down-cutting of the stream valleys has exposed, at numerous

[1] Dupont, *op. cit.* [2] Cornet, *op. cit.*, XXI, 211.

places, the summits of the greater elevations of this ancient surface. While the contact is poorly exposed, the basal beds are seen to be nowhere coarsely conglomeratic nor to contain many pebbles. The well-rounded pebbles consist of quartz, chert, and granite, all probably derived from the so-called pre-Cambrian series. They are usually confined to the twenty feet immediately above the contact, although in instances they occur considerably higher.

Between Luebo and Lusuna, where the base of the series is not seen, conglomeratic beds or lenses were noted interbedded with sandstone. In the Lualaba Valley within the zone of the Maniema a basal conglomerate, which will be described later, is frequently exposed in the valleys of the streams.

The vertical range between the base and top of the Lubilache is probably somewhat greater than 1,500 feet. At no one locality however, known to the writers, is this entire thickness exposed. In the upper Kasai region, between Luebo and Djoka Punda, monadnocks, principally of massive red sandstone of this series, rise 400 feet above the general plateau level, and 700 feet above the river at the places named, thus exposing approximately 700 feet of this formation.

In the Maniema the base of the series is considerably higher than in the Kasai region, the base averaging 2,000 feet in the former, and 1,550 feet in the latter region. As the beds were deposited in what appears to have been one and the same lake, this difference in elevation is due probably to north-and-south faults parallel to Tanganyika Lake. These successively have raised the country from west to east upward. Evidence of this is seen in the isolated outlier of sandstone in the Luiko Valley, later to be described (see p. 691).

Initial dips up to 5 or even 10 degrees were noted in the zone of the Maniema, particularly where the sandstone occupies ancient fjords extending up into the old mountains, and a slight initial dip occurs away from the mountain masses toward the center of the larger basins of deposition. For the most part, however, the formation is essentially flat-lying, and with few exceptions the dip can be measured only in feet per mile and not in degrees.

AGE OF THE LUBILACHE

Studt,[1] from general stratigraphic relations, considers the Lubilache in the Katanga to be the equivalent of the Stormberg member (Trias) of the Karoo. This correlation is confirmed by fossils collected by us. While these plant and animal remains are of a fragmentary character, they are nevertheless sufficient to place rather definitely the horizons from which they were collected. Dr. E. O. Ulrich, of the U.S. Geological Survey, kindly determined the fossils, and places the age of the series probably in Jura-Triassic time. Fossils were found by us, and described by Dr. Ulrich as follows: Shale from Niangwe 200 feet above base of Lubilache series: "Fragments of plants undeterminable."

Chert from Sandy Beach (on Congo, 130 miles above Leopoldville) perhaps 150 feet above base: "Probable broken sponge spicules and suggestions of branching sponges."

Limy shales ten miles below Stanleyville and 150 (?) feet above the base of series, Dr. Ulrich states:

> These are crowded with Ostracoda and with these fewer bivalved phyllopods and fragmentary dermal ossicles of ganoid fishes. So far as observed the Ostracoda belong to fresh and brackish water species of *Cypris* and *Candona* and perhaps other genera of Cypridae. Unfortunately the form in these Ostracoda is very similar in species, ranging from Pennsylvanian on to recent times. But the alliances of your specimens seem to be rather nearer Mesozoic species than to Tertiary. . . . .
>
> With the Ostracoda I find a single valve of a neat *Estheria*. The surface ornament appears minutely radiate under a hand lens but more closely examined is found to consist of sharp radially disposed bars crossing the flat spaces between the concentric ridges. This type of ornament is found in two recent species (*E. donaciformis* and *E. similis* Baird) and also in two Mesozoic species (*E. elliptica* Dunker and *E. subquadrata* Sowerby), but the Stanleyville species evidently differs in outline from all of these and doubtless represents a distinct, probably new, species. The fish remains are too fragmentary to be determined.

Mr. R. Kotska, prospector of the Lower Congo–Katanga Railroad, found a fossil crustacean at Sangula at the confluence of the Buschinmai and Sankuru rivers. This specimen has been turned over to us through the kindness of officers of that company. The prospector, a man with considerable geological knowledge, describes

[1] *Annales du Musée du Congo*, série II, "Katanga" (Bruxelles, 1908), 14.

the rock as flat-lying, "grès tendre," the common Belgian name for the Lubilache formation. The matrix in which the fossil occurs is typical of the soft sandstone seen by the authors at Lusambo, 60 miles to the north of Sangula. There is then no doubt in the minds of the writers that this is from the Lubilache formation. Concerning this fossil Dr. Ulrich says:

> It is a bivalved crustacean, apparently of the genus *Estheria:* and so far as known to me the largest species of this genus yet found. The species seems distinct from all the described forms.
>
> Looking over the fossils again, my belief has grown to conviction that the bed from which these fossils were procured is Mesozoic and Jura-Triassic, rather than later.

While the fossils are by no means strongly indicative of the climatic conditions under which they lived, Dr. Ulrich states that if they indicate anything concerning the climate it would be that it was relatively moist and rather cool. The water was either fresh or brackish.

DEPOSITION OF THE LUBILACHE

The Lubilache formation was deposited in a Triassic lake of fresh or brackish water, which may have been connected with the ocean. On the railroad at kilometer 115, in the Lower Congo, residual bowlders of what one of us (S. H. B.) takes to be the Lubilache formation, occur on the west side of the present divide of the plateau, commonly called the Crystal Mountains. It is hence more than probable that this ancient lake was once connected with the ocean by one or more straits. From the present distribution of the Lubilache beds this lake was at least 900 miles in diameter, and was probably much larger. The bed of the lake was an undulating surface, and the body of water was surrounded by low land to the west, north, and south, but with at least hilly country to the east. These eastern hills in instances must have been 2,000 feet high. Between them ran valleys, some of which appear to have been deep and abrupt enough to have been worthy of the name of "fjords." While the Lubilache was being deposited it is more than likely that the central part of the lake basin around the present Lake Leopold II was a sinking area. At no time does the lake appear to have been deep, except in certain valleys extend-

ing into the mountains. Cross-bedding is common, as are rapid changes from sandstone to shale, probably best to be interpreted by current scouring. The nature of the sediments indicate deep disintegration of the rocks near the shore, while from the fossils Dr. Ulrich is inclined to believe the water to have been at least cool.

LUBILACHE IN THE ZONE OF THE MANIEMA

In the Maniema zone in the Lualaba Valley and in the valleys of its tributaries, west of the Eastern Frontier Mountains, the Lubilache covers a large area, as shown in Fig. 2. Within the zone isolated hills and mountain groups of older granites, gneisses, schists, and folded sedimentary rocks rise above the dissected plain of the flat-lying series. These older rocks probably stood as islands in the lake in which the Lubilache was deposited.

The general character of the beds of this series has been described, but a more detailed description of the basal beds will be given, as it is at this horizon that evidences of glacial action were noted.

LUBILACHE BASAL CONGLOMERATE IN THE MANIEMA

The basal beds are best exposed along the Lualaba River, and the lower Lulindi, and here they have an entirely different character from elsewhere in the Maniema and other districts, as known to the writers. Indeed very coarse conglomerates at the base of these flat-lying sandstones and shales are confined to the immediate valleys of these streams. Elsewhere where the conglomeratic phase occurs the pebbles are rarely over an inch in diameter and sparsely distributed. This is true even where conglomeratic beds occur around the hills of granites, schists, and other older rocks.

In the immediate valley of the Lualaba and lower Lulindi rivers, between 3° 30′ and 5° south of the equator (our work did not extend south of the 5th parallel) the basal 5 to 20 feet of the Lubilache is an exceedingly coarse conglomerate. This conglomerate is morainal material, deposited by a tongue of a glacier which followed down the Lualaba Valley probably prior to its becoming a gulf of the great body of water in which the Lubilache was deposited. The morainal matter appears to have been but slightly reworked by the waters of the lake.

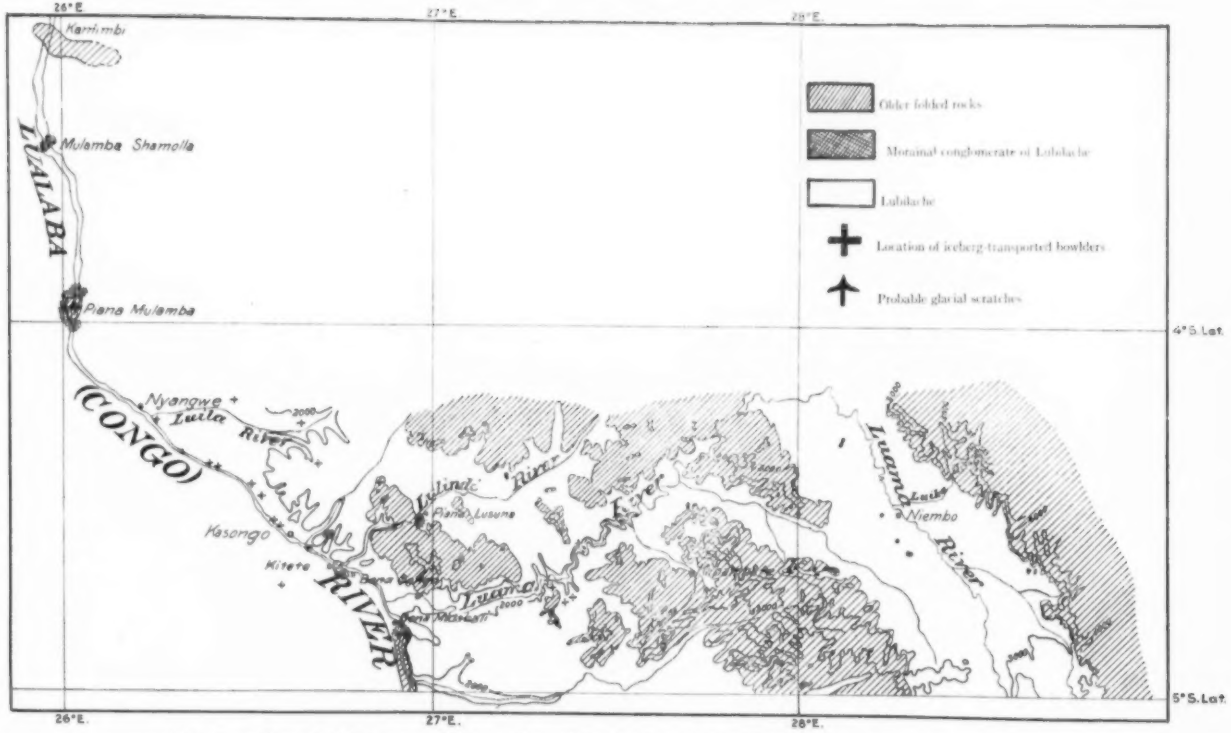


FIG. 2.—Map of Maniema. Scale $\frac{1}{2,000,000}$ (after indicated reduction); contour interval 1,000 feet

Before the formation of the great interior lake or sea in which the Lubilache was deposited the Congo Valley was probably a most important depression and after the subsidence the upper portion of the valley formed a wide but rather shallow gulf with arms reaching in instances into valleys of the eastern mountain range itself. A small isolated remnant of flat-lying sandstone having the general lithologic character of the upper beds of the Lubilache, as exposed in the Maniema, was found in the Eastern Mountains in the Luiko Valley. This outlier is only a few feet in thickness, and lies in a small tributary valley on an uneven, eroded surface of gneiss. Its elevation above sea-level is about 4,800 feet, or nearly 2,000 feet above the highest horizontal rocks known in the region, the sandstone forming Niembo Mountain near Niembo (Fig. 2). This great difference in elevation is due to profound north-and-south faulting along the western front of the Eastern Mountains, but the presence of horizontal sandstone beds in a small valley at a considerable distance from the main area of flat-lying rocks is unquestionably due to its having been deposited in an antecedent valley, the sides of which protected it from complete removal by erosion. This outlier, and the residuals of apparent Lubilache in the Bas-Congo, show that this formation once had much wider distribution than at present.

A type of the Lualaba River basal beds is exposed along the Lulindi River, just downstream from the crossing of the telegraph line, and near the village of Piana Lusuna. This is fifteen miles from the present Lualaba River, and 275 feet above it at Kasongo. The older rocks unconformably underlying the Lubilache are not exposed here, but typical basal beds occur for 200 feet laterally along the river. The matrix of the conglomerate is a yellow, incoherent, fine-grained, slightly argillaceous sandstone. The exposure is apparently flat-lying. Small bodies are wholly without bedding, others are thinly laminated, while still others have a swirly bedding, the thin laminae curving in concentric bands. Cross-bedding is not rare. The distribution of the bowlders and pebbles is patchy; areas 2 to 40 feet across being without pebbles, while between are heavily conglomeratic areas. In the same conglomeratic mass coarse sand and bowlders 4 feet across occur. The smaller pebbles

are usually well rounded; the larger are angular or only roughly rounded; the medium-sized bowlders, those from 2 to 6 inches in length, are three or four cornered and often striated.

The striations are especially well seen on dense, close-textured rocks, quartzite for example (Plate I). These can scarcely be other than glacial striations. While through desert erosion somewhat similar scratches are produced, they are too abundant here on a single bowlder, and the familiar tiny crescentric fractures (nicks), caused by the striking of one bowlder by another in descending the cloud-burst swept valleys of arid regions, are absent.

With but slight variations this description would answer for the exposures on the Lualaba River at the Kitete Rapids where the Lubilache is in contact with quartzite; at Bena Songo and Bena Matabali Rapids; at Piana Mulambo where the Lubilache lies on slaty quartzite more or less folded; and at Mulambo Shamola. The principal and most constant differences lie in a slight variation in the character of the matrix, which varies in color from whitish yellow to greenish gray or dark gray, and in the degree of consolidation. The matrix, which is usually incoherent, is well consolidated at Piana Mulambo and Mulambo Shamola. At Bena Songo the irregular distribution of the bowlders is well seen, many occurring for 100 feet laterally, and none in the next 100 feet.

Where the underlying older rocks are exposed the bowlders derived from them are more abundant and more angular than the bowlders of other varieties. The bowlders and pebbles consist of quartzite, of granites and gneisses, of limestones, etc. It is worthy of note that at the most northerly of these outcrops of basal conglomerates at Mulambo Shamola, the larger pebbles are but six inches in diameter. There are at all other localities great bowlders two to three feet in diameter, of rocks not known to occur in the immediate vicinity, that is, large bowlders which have been transported considerable distances. Typical examples of the contact of these basal beds with the older rocks are seen in Fig. 3, A and B representing respectively the contact with quartzite at the head of the Kitete Rapids, and the contact with slaty quartzite at Piana Mulambo.

PROBABLE GLACIAL SCRATCHES

Piana Mulambo is situated on the Lualaba River about fifty miles northwest of Kasongo (Fig. 2). One-quarter mile east of the house of the transport agent of the Grand Lakes Railroad at this village is a swift rapid in the river. On the west bank of the river, at the lower end of the rapids, highly inclined slaty quartzite beds are at the same elevation as the base of the Lubilache at the house mentioned. Fig. 3B represents the contact one mile south of the house. The slaty quartzites, owing to the differences in resistance to erosion of their beds, usually weather as sharp-crested ridges and saddles, but here and there are flat surfaces. On the upper surfaces and never on the sides of these flat exposures of the older rocks are peculiar gouges and scratches (see Fig. 4).

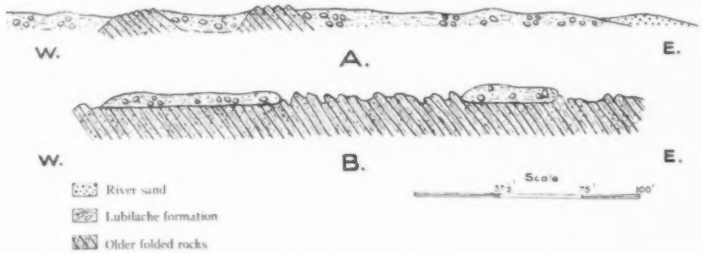


FIG. 3.—Contacts of Lubilache and older rocks on Lualaba River. A, Kitete Rapids; B, Piana Mulambo Rapids.

Coursing a little east of north and west of south these gouges and scratches have a rude parallelism. Some are cylindrical depressions from one to five feet long, and from one-half to three inches wide and deep. The ends are as a rule cigar-shaped and the surfaces of the grooves are striated with fine scratches from $\frac{1}{16}$ to $\frac{1}{4}$ inch apart. At the southern end is frequently a bowl-like depression, more deeply cut than the rest of the gouge. Local smoothings of the rocks occur finely striated with parallel scratches and in direction similar to the gouges described. At one place are three crescent-shaped gouges which course from east to west, with the concavity to the south. These, which resemble "crescentric gouges," are four inches in length, the central one being deepest and broadest (see Fig. 4).

These gouges occur level with the contact elsewhere, and do not resemble any river-worn scratches with which we are familiar. The grooves, crescentric gouges, and the finely striated planed surface appear to be of glacial origin, and indicate that the glacier once extended to at least this point, or to 4° south latitude. The glacier, from this evidence, advanced from south to north.

ERRATIC BOWLDERS

In the immediate Lualaba and Luama valleys in the Maniema, and for several miles on either side between Nyangwe and the

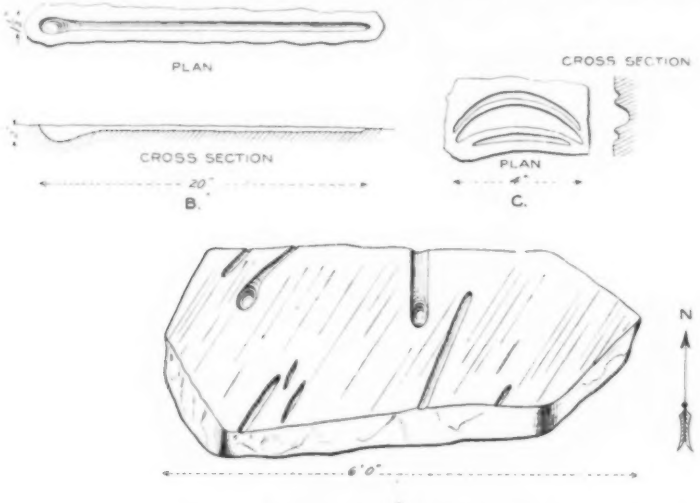


FIG. 4.—Probable glacial grooves and scratches on Paleozoic slaty quartzites, Piana Mulambo Waterfall, Lualaba River.

5th parallel south, the shale of the Lubilache has sparsely and irregularly scattered through its mass, pebbles and bowlders with a maximum diameter of five feet. These bowlders are not known to occur within the large areas of the Lubilache away from these rivers. They are usually well rounded, and consist of granites, quartzites, diorites, and other older rocks. There is in no case any change in the fineness or character of the well-laminated shale immediately surrounding these isolated bowlders.

The laminae of the shale are concentric with the form of the bowlders, being slightly arched over, and greatly bowed under them, as if they had been dropped from considerable heights into a plastic mass.

Within the limits defined these bowlders occur at numerous localities, as shown in Fig. 2, at stratigraphic positions from 0–200 feet above the base of the formation. Two exceptions should be noted: At Bena Tomba, latitude 4° 30′ S., on the bank of the Lufubu River, and at Tubila on the Lualaba, latitude 1° 30′ S., bowlders of older rocks lie upon the surface. The underlying rock is the Lubilache shale. The source of these bowlders is not known; they may have weathered from the shale, or they may have been carried to the points named by the natives, by whom such hard rocks are used in grinding foodstuffs.

The largest bowlder noted is of granite and was found by Smith, about one mile north of the Luila River. This bowlder measured $5\times3\times3\frac{1}{2}$ feet. Numerous other large bowlders were noted in the shale northeast of Kasongo.

From the fineness of the inclosing shale, the size of these bowlders, and their great distance in many cases from their source, it is evident that they were dropped from some object floating on the surface of the body of water in which the Lubilache was deposited. They could have been transported in but one of two ways: (1) by being imbedded in the roots of floating trees, or (2) by being carried by icebergs.

That bowlders of such enormous weight could be transported in the roots of floating trees is improbable. Furthermore, the shales of the Lubilache are practically barren of vegetable remains, particularly fossil tree trunks; absolutely none of the latter having been noted. The bowlders are numerous along the Lualaba and are known nowhere else in the formation. It is scarcely conceivable that the shores of this portion of the basin of deposition were alone bordered by trees capable, when swept into the lake, of transporting bowlders of several tons weight in their roots. Moreover, fragments imbedded in tree roots are usually not only angular or subangular, but also small and of weathered rock; while in all cases the erratic bowlders of the Lubilache shale are rounded or

subangular, and are frequently large and fresh. Further, at several places the bowlders are in excess of what can be considered the load of one tree. In shales elsewhere in the world which are known to have been deposited in lakes or seas with tree-lined shores, similar bowlders occur in but few instances.

We believe, then, that these bowlders were transported by icebergs, derived from glaciers, and which melted where perhaps arrested in their courses by cross-currents.

Nyangwe was apparently the northern limit to which these icebergs reached, although below Nyangwe the immediate Lualaba (Congo) Valley only was examined. From Nyangwe to 5° S., however, in almost every mile of Lubilache exposures traversed, these erratics were noted. As the morainal conglomerate extends south of Nyangwe, we have perhaps evidence here of the southward retreat of the glacier in early Lubilache times.

RÉSUMÉ OF EVIDENCES OF GLACIATION

It is concluded from the evidence given above that during Triassic time at the beginning of the deposition of the Lubilache series, a glacier, or glaciers pushed in a tongue down the present valley of the Lualaba River; from the fact that large bowlders, probably dropped by icebergs, are found at least 200 feet above the base of the formation, it is believed that long after the glacier had retreated toward the south, glaciers still existed to the southeast. This glacial epoch, therefore, must have been of a considerable duration.

The glacial features presented by the Lubilache formation contiguous to the Lualaba Valley in the Maniema are:

1. Striations, having the characteristics of glacial striations, on pebbles in the basal conglomerate of this series, indicating morainal origin.

2. The tongue-like form of the basal Lubilache beds in the Lualaba Valley, and the character of this conglomerate, including the size of the bowlders, the lack of assortment, the patchy arrangement of the material, and the preponderance of bowlders of local origin.

3. Erratic bowlders, presumably dropped by icebergs, occurring

in shales of this series as far north as the latitude of Nyangwe which have been seen only near the Lualaba Valley.

4. Probable glacial scratches, crescentric gouges, and smoothings on the surfaces of older rocks upon which the Lubilache was laid down.

The presence of glaciers being, in the writers' mind, proved by the above evidence, it remains to determine, in so far as possible, the character of the glaciers, the climatic condition under which they existed, their extent, and their relation to the Permo-Carboniferous glaciers of South Africa.

AFRICAN EQUATORIAL GLACIERS OF THE PRESENT DAY

Chamberlin and Salisbury[1] state that in equatorial regions the snow line has an altitude of from 15,000 to 18,000 feet.

Small mountain glaciers are known on three of the highest peaks of equatorial Africa. Hans Meyer[2] found on Kilima Njaro (3° S.) small glaciers with lower limits at an elevation of 4,300 meters (14,100 feet). On Ruwenzori (1° N.) E. S. Moore[3] found several glaciers with the snow line at 13,500 feet above sea-level.

Scott Elliot[4] gives the snow line on this same mountain as 15,500 feet. J. W. Gregory[5] found glaciers on Mount Kenia situated on the equator. The lower ends of these glaciers are 15,500 feet above sea-level; the snow line being at 16,000 feet. Scott Elliot[6] believed that formerly glacial action extended to 5,200 feet on Ruwenzori. Gregory[7] found evidences of old glaciers on Kenia at about 10,000 feet, and Meyer[8] states that on Kilima Njaro the glaciers once pushed down to lower levels. Among certain geographers the conclusions concerning these Pleistocene glaciers are doubted.

[1] *Geology*, I, 246.

[2] Hans Meyer, *Verhandlungen der Gesells. für Erdkunde der Berlin*, XXVI (1899), 100.

[3] *The Tanganyika Problem* (London, 1903), 102.

[4] *A Naturalist in Mid-Africa* (London, 1896), 175.

[5] *Geographical Journal*, IV (1894), 419–20.

[6] Elliot, *op. cit.*, 172.

[7] Gregory, *op. cit.*

[8] Meyer, *op. cit.*

PROBABLE ELEVATION OF LUBILACHE BEDS WHEN DEPOSITED

The base of the Lubilache formation at Luebo at the present day is 1,475 feet above sea-level. In the Maniema, due to uplift by north-and-south faults, the basal beds lie at a higher elevation (1,800 to 2,400 feet), while near Lake Leopold II (1,110 feet), through subsidence of the beds, the country rock is well up in the Lubilache. It is believed that the elevation of the basal beds at Luebo is considerably above that of the lake bottom in which the Lubilache was deposited. It has before been mentioned that residuals of what appears to be the Lubilache formation were found in the Lower Congo, indicating that the lake was probably once connected with the ocean. Other evidence also points to the uplift in later geological times of the Crystal Mountain region to an elevation of 3,400 feet above sea-level. On the coast there is an indistinct zonal distribution of the Tertiary and Cretaceous sedimentary rocks, the later being farther inland. The Crystal Mountains themselves are a peneplain, which has been uplifted presumably by faults coursing west of north and east of south. The Congo River valley through the Crystal Mountains is young topographically and indicates recent uplift, and yet the amount of erosion which the peneplain has suffered would lead one to place its development back at least as far as the Cretaceous. At some time then during or prior to the Cretaceous we may believe the Congo basin to have been practically at sea-level. All evidence at hand indicates that the Lubilache formation was laid down in a lake of which the bed was at, or but slightly above, sea-level.

Only to the east did high hills arise, and from the lack of bowlders in the Lubilache immediately surrounding these hills, it is doubted if they reached a maximum elevation of over 2,000 feet above the lake surface.

SIZE OF GLACIER

The known extent of the morainal basal conglomerate in the Maniema (at least 100 miles from north to south) is many times greater than any tropical glacier now existing. Further, if the bottom of the Lubilache lake was at as low an elevation as we believe it to have been, we must rank this glacier in size with glaciers of the Malaspina type, if not with continental glaciers.

CLIMATIC CONDITIONS

Dr. Ulrich is inclined to believe the fossils indicate cool waters, and the writers think that, while the glacial conditions were induced partially by the altitude of the region in which they formed, they were largely due to climatic changes. At present, due to faulting comparatively recent in the geological sense, some of the mountains between the Lualaba River and Lake Tanganyika are 9,000 feet high. It is doubtful whether as great elevations existed in the Maniema during Lubilache time.

LOCATION OF THE GLACIER

The position of the glacier can be located only in a most general way. It appears to have been south of the Maniema.

The disappearance of the glacial conglomerate and the iceberg-borne bowlders to the north indicates that the source of the glacial material was to the south. Of similar import is the fact that the supposed glacial striations have a north-and-south orientation, while the concavity of the crescentric gouges indicates a movement from south to north.

Toward the south the work of the writers extended only to the fifth parallel. Professor Cornet's work in 1901–3 was within the Katanga, between latitudes 8° and 12° S. and longitudes 28° to 23° 31′ E. Between Professor Cornet's work and the fifth parallel, lies a considerable area in which the geology has not been studied even in reconnaissance.

To the southeast of Kabambare are mountains where these glaciers probably existed in Lubilache time, reaching today elevations of 9,000 feet; in Lubilache time they were presumably not so high. The Luama River heads in these mountains, and as the erratic bowlders are found along its course, as well as that of the Lualaba, it is possible that the valley then existed and that the glacier pushed north and then west and northwest from these mountains to the Lualaba.

Another possible but not probable location of the glaciers is found in the mountains to the northeast of Kasongo, the glaciers descending the Lulindi River to the Lualaba, thence being deflected northward along its valley. Northwest of Neimbo (Fig. 2) and

in other places in the Kabambare region at the contacts between beds of Lubilache and the older rocks, conglomerates are notably absent, which argues against a source of the glacier in the general region of Kabambare.

RELATION TO PERMO-CARBONIFEROUS GLACIATION IN SOUTH AFRICA

It has long been recognized that the Dwyka conglomerate at the base of the Karoo formation in South Africa is a glacial moraine, more or less reworked by water. These continental glaciers of Permo-Carboniferous age lay to the north of Cape Colony,[1] and from this center pushed southward.

The most northerly occurrence[2] of this conglomerate is in latitude 25° 40′ S.

The Stormberg beds, with which former Congolese geologists have correlated the Lubilache, is a much younger formation of Rhaetic age (close of Triassic); while, as Cornet[3] believes, the earlier Karoo members are probably represented by red sandstones named by him the "Kundulungu" formation. The fossil evidence here presented strengthens greatly this correlation.

When the Lubilache lake formed, a tongue of morainal material probably covered the Lualaba Valley. The bowlders, however, composing it are believed to be too fresh for it to have been the deposit of a Permo-Carboniferous glacier. Were such the case, weathering throughout Triassic time would almost certainly have destroyed the bowlders. Moreover, well up in the Lubilache formation iceberg-transported bowlders occur, indicating the presence of glaciers at that time somewhere to the south.

The source of the glaciers at the two periods appears to have been in the same general region, and it is possible that, in some area in northern Rhodesia or southern Belgian Congo, glaciers existed for the greater part of Permian and Triassic time.

[1] A. W. Rogers, *The Geology of Cape Colony* (London, 1905), 413.

[2] See map of Transvaal, by T. H. Hatch and G. S. Corstorphine, *The Geology of S. Africa*, London, 1905.

[3] Cornet, *op. cit.*, 413.

RÉSUMÉ

The geology of Central Africa is as yet too little known to discuss the possible bearing of this ancient glacier within the tropics upon the broad problems of general and glacial geology. It suffices to state that there appears to be reason to believe that in Triassic times, when tropical life flourished in polar regions, a temperate or coolish climate existed to the west of Lake Tanganyika in Central Africa 4° 30′ from the equator.

Knowlton[1] in describing the Triassic flora states that it indicates that there were "no or but slight seasonal changes due to alterations of hot and cold or wet and dry seasons." It was "on the whole a moist, warm, probably at least subtropical climate."[2] He mentions that Triassic floras have been found on the east coast of Greenland, and in Spitzbergen.

July 9, 1910

EXPLANATION OF PLATE

PLATE I.—Glacial-scratched bowlders; basal conglomerate. Lubilache formation, Lulindi River, near Piana Lusuna.

[1] *Journal of Geology*, XVIII, 107.

[2] *Ibid.*, 106.

THE PUERCO AND TORREJON FORMATIONS OF THE NACIMIENTO GROUP[1]

JAMES H. GARDNER

CONTENTS

Introduction
History of the Puerco
History of the Torrejon
Naming of the Nacimiento
Geology of the type-locality
Fossils
Correlations
Summary
Bibliography

INTRODUCTION

The formations of the Nacimiento group are subjects of much interest to science because of the character of their vertebrate faunas and the positions they occupy in the time-scale of geologic history. The fossil mammals of the two formations have been carefully discussed by eminent paleontologists and yet but little is known of their areal distribution or stratigraphic occurrence. This paper is accompanied by the first contribution of detailed geologic mapping in the area of their type-localities, and is the result of research which has brought forward some important facts and thrown considerable light on the problem of their faunal and stratigraphic relationships.

The Nacimiento group was deposited during that long period of fresh-water conditions which prevailed over the greater part of western North America at the ending of the Cretaceous and the beginning of the Tertiary periods. In recent years paleontologists have considered the group as being earliest Tertiary in age, and thus marking the beginning of the Eocene series.

It is intended in the following pages to review the formations of this group, their correlations, etc., from the first discoveries to the present time and to set forth clearly the facts of their stratigraphic

[1] Published by permission of the Director of the United States Geological Survey.

relationships in the light of new evidence; to present the first detailed geologic map of the upper Rio Puerco region; to discuss the physiographic changes which have taken place in that district between the close of the Cretaceous and the beginning of the Wasatch (Eocene); to present a list of fossil vertebrates with photographs of certain species apparently new to science; and to furnish a bibliography relating to the subjects under discussion.

HISTORY OF THE PUERCO

The Puerco formation was first described by Professor E. D. Cope in the *Annual Report of the Chief of Engineers to the Secretary of War* for the year 1875. His report deals with the geology of that part of northwestern New Mexico examined by him during the field season of 1874 when he discovered the Eocene deposits of what has since been called the San Juan Basin, from the river of that name which crosses it. This basin is in the extreme northwest corner of New Mexico and southwest corner of Colorado (see Fig. 1). On this map, the area inclosed by heavy black lines represents that examined by the writer in 1907 and is a miniature of the larger map presented herewith. The area described by Cope in connection with his Puerco formation is mainly along the east side of this district.

Inasmuch as the original description of Cope is of prime importance in the present discussion it is well here to quote his remarks on the Eocene Plateau or that portion of the San Juan Basin just west of the Sierra Nacimiento Mountains. In the following quotation, the names of formations referred to by Cope as correlated by the writer with those of the present time, are placed in brackets.

EOCENE PLATEAUS

West of the hog-back of Cretaceous No. 3 ["Laramie"] at an interval of perhaps two miles, at a point just north of the Gallinas Mountain, a sandstone bluff [Wasatch] presents a bold escarpment to the northeast. This is the angle of a mass of rock whose eastern face extends southward parallel to the mountain-axis, and whose strata dip first 15° and then 10° south, and soon disappear beneath a similar mass. This series [Wasatch] also presents an escarpment to the northeast, and its beds also dip 10° south, nearly opposite the cañon of the Gallinas. This façade rises to from 600 to 900 feet elevation, and is cleft to the base by a deep gorge, the Cañoncita de las Vegas. I traversed this fissure, passing entirely through to the elevated country to the westward. Six miles from its mouth is a large pool, fed by a spring known as the Mare's Spring. The cañon is narrow,

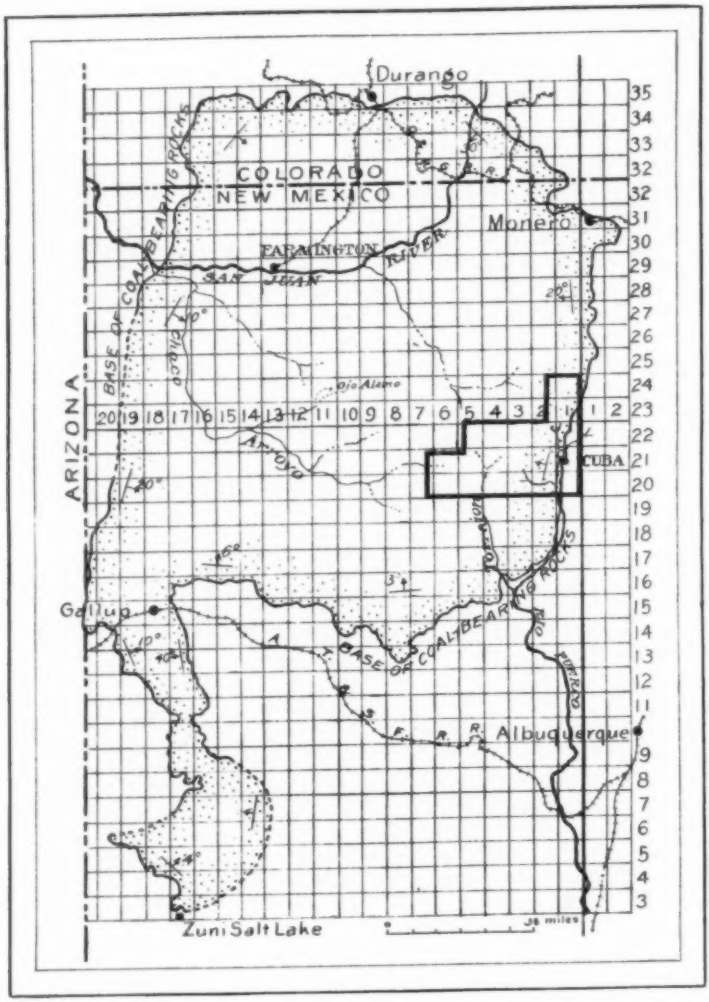


FIG. 1.—Sketch map showing relation of the Puerco-Torrejon locality to the San Juan Basin.

and the walls almost perpendicular. They are composed at the "puerta," or entrance, of a moderately hard, reddish-brown sandstone. The cañon is twenty miles in length, its bottom has a gentle rise; and as the sandstone has a gentle dip toward the west as well as south, its upper beds reach the level of the bottom at about the middle of the length of the cañon. Above them softer beds [Wasatch] appear, alternating with strata of sandstone; the beds are first gray, but others soon appear which are striped with red. The red-striped marls increase in relative thickness toward the west, and the sandstone strata diminish until at the head of the cañon the high lands fall off in masses of hills of bright-colored marls eroded into rounded and picturesquely formed hills. These extend in a long line to the north and the south, facing westward. To the west, a wide, elevated plain spread before us, varied with a few hills, and stretching away with a gentle slope to Cañon Largo and the country of the San Juan River. The discovery of the variegated marls was one of no little interest to the writer, inasmuch as I had made special efforts to find Eocene beds in this region, and they were now crowned with success. The position of these marls, with their close physical resemblance to the Wasatch beds of Bear River, Wyoming, together with the evidence furnished by a lower molar of Bathmodon, discovered by my guide, indicated that I had discovered the sediments of the great body of fresh water which during successive stages of the Eocene period occupied the drainage-basin of the Great Western Colorado. The thickness of the strata exhibited in the walls of the Cañoncita de las Vegas, I estimated at 1,200 feet.

On leaving the mouth of this cañon, and proceeding southward, the southern dip of the red sandstones [Wasatch] brings their summit to the ground-level in about ten miles' distance. The red and gray marls with alternating beds of white and yellowish sandstone [Wasatch] appear on their summits, and at a point twenty miles south of the cañon, form a mass of badland bluffs of from 600 to 1,000 feet elevation. This escarpment retreats and then turns to the east, forming an extensive horseshoe, the circumscribed area being occupied with hills and picturesque masses of sediment, with all the peculiar forms and desolation of badland scenery. I remained in camp for about a month near this circle, and obtained many fossil remains of vertebrates [Wasatch]. Ten miles south of this point another horseshoe of badlands covers an extensive area, and proved to be as rich in fossil remains [Wasatch] as the first. Here I made my second camp, remaining in it for three weeks. The southern boundary of the northern tract extends to within six miles of the Cretaceous hog-backs, while the corresponding part of the second approaches nearer, forming a line of bluffs of considerable height running north and south parallel with, and half a mile from, the hog-backs. Beyond the Puerco divide, hills of this formation rise on both sides of the trail, and near the Ojo de San José, the Eocene beds repose on the foot of the Nacimiento Mountains several miles to the east.

Below the sandstones which form the portals of the Cañoncita de las Vegas, another stratum of marls [Puerco] shows itself in hills of 100 feet and higher, in the sage-brush plain that separates them from the Cretaceous hog-backs. They

are soft and of mixed black and dark-green colors near the locality in question, and capped by light and yellowish sandstones. These are the lowest beds of the Eocene, and I traced them for forty miles to the south along the belt of country intervening between Cretaceous No. 4 ["Laramie"] and the reddish sandstone [Wasatch]. At the locality just mentioned they conform to the sandstones above, having a dip of 10° southwest, while they do not conform to the hog-back of Cretaceous No. 4 ["Laramie"], the nearest available outcrop, which dips at 25° west. Farther south this marl is represented by low hills of generally lighter color. Near Nacimiento it has an increased importance, as it rises both to the east and south. The valley of the Upper Puerco is excavated in it for some distance, and its blackish, greenish, and gray hills are seen on both sides of the river. At a point on the river about six miles below the village of Nacimiento, the lower sandstone of the Eocene forms a perpendicular bluff, which terminates in an escarpment of 500 feet elevation facing the south. The red-striped marls [Wasatch], having acquired a gentle northern dip, disappear from view some miles to the north, and the termination of the underlying sandstones warned us that we were approaching the southern border of the basin.

The border of the sandstone turned to the west at this point, the line of bluffs continuing as far as vision extended. Below and south of it, the varied green and gray marls formed the material of the country, forming badland tracts of considerable extent and utter barrenness. They formed conical hills and flat meadows, intersected by deep arroyos, whose perpendicular walls constituted a great impediment to our progress. During the days of my examination of the region, heavy showers of rain fell, filling the arroyos with rushing torrents, and presenting a peculiar character of this marl when wet. It became slippery, resembling soap in consistence, so that the hills were climbed with great difficulty, and on the levels the horses' feet sank at every step. The material is so easily transported that the drainage-channels are cut to a great depth, and the Puerco River becomes the receptacle of great quantities of slimy-looking mud. Its unctuous appearance resembles strongly soft-soap, hence the name Puerco, muddy. These soft marls cover a belt of some miles in width, and continue at the foot of another line of sandstone bluffs, which bound the immediate valley of the Puerco to a point eighteen miles below Nacimiento. Here the sandstone again turns to the westward presenting a southern escarpment of 500 to 1,000 feet elevation. I could not be sure whether this sandstone is identical with that of the escarpment twelve miles north, but suspected it to be such. [It is a lower sandstone and is Mesaverde.] Immediately south of it, low hills of Cretaceous No. 4 (?) [Mancos] extend across the Puerco [River] and continue south of the Eocene (?) bluffs at a distance of a mile or two with a western strike. They were as elsewhere of a soft yellowish sand and clay, including shale beds, and contained abundance of *Inoceramus*, like those found on the Gallinas.

Ten miles to the southward, the underlying Cretaceous beds are capped by a horizontal table of basalt (Mount Taylor flow) thus forming a mesa, through which the Puerco passed in a cañon. I supposed this to be the forerunner of

the great basaltic plateau which, according to Lieutenant Wheeler, constitutes the country south of the Rio Chaco for a great distance, one of little promise to the agriculturist. The season being well advanced, October 22, I thought best to commence the return march, which we accordingly did.

The soapy marls, or, as they may be called, the Puerco marls, have their principal development at this locality. I examined them throughout the forty miles of outcrop which I observed for fossil remains, but succeeded ir finding nothing but petrified wood. This is abundant in the region of the Gallinas, and includes silicified fragments of dicotyledonous and palm trees. On the Puerco, portions of trunks and limbs are strewn on the hills and ravines; in some localities the mass of fragments indicating the place where a tree had broken up. At one point east of the river I found the stump of a dicotyledonous tree which measured five feet in diameter.

As already remarked, the Puerco marls belong to the Eocene series in their strict conformability to the superincumbent rocks of that age. They do not appear to represent the Fort Union or Lignite beds of northern Colorado and the North, as they differ in almost every respect. They contain no lignite nor coal, although their occasional black color may be due to a small amount of carbonaceous matter. They have no resemblance to the Fort Union beds in mineral character or fossils. I conclude, as a result of the investigation, that the latter formation has no existence in this part of New Mexico. The presence of such quantities of petrified wood gives weight to the probability that the Puerco marls are a lacustrine formation.

The geography of the greater part of the district referred to in the above quotation is shown on the topographic geologic map presented herewith. This map does not extend far enough northward by about seven miles to include the Canyoncita de las Vegas mentioned by Cope; however, that drainageway was identified in the geologic study of the general district and is now shown on the new topographic sheet of the Gallina quadrangle by the U.S. Geological Survey.

As shown on the map, about five miles west of north of Gallina the base of the Wasatch formation swings away from the Cretaceous hog-backs forming the south boundary of the "extensive horseshoe" referred to in the quotation from Cope where he obtained many fossil remains of vertebrates. He mentions another horseshoe ten miles south of this also rich in fossil vertebrates; the southern area is about four miles north of what is now known as La Jara P.O. However, the horseshoe here is not formed by the extreme base of the Wasatch as is the case farther north. In the La Jara district the present writer obtained numerous vertebrate teeth and skeletal remains.

In the last paragraph of the above quotation of Cope's description, he states that the "Puerco marls" do not appear to represent the Fort Union or "Lignite beds of the North"; in writing later on the subject for the Geographical Survey west of the One Hundredth Meridian (*Annual Report* [1877], Part II, p. 18) he remarks that these beds "may represent the Fort Union or Lignite beds of the Upper Missouri some of whose strata they resemble in color and consistence." These remarks are noted with interest since recent explorations have shown that Torrejon fossils, which characterize the upper part of Cope's original Puerco, do occur in the Fort Union beds of Montana.[52, 68] Cope states that he did not succeed in obtaining fossil remains from the Puerco, other than petrified wood, and mentions finding numerous fragments of silicified limbs and trunks of dicotyledonous and palm trees, among them one stump which measured five feet in diameter. (See Fig. 7, this paper.) These remains are indeed abundant in this vicinity; on the summit of the mesa two miles west of Cuba post-office, which is the village Nacimiento, there are some ancient stone ruins which were built in large part of specimens of silicified wood.

Although Cope was unable to find satisfactory fossils in the Puerco at the time of its discovery in 1874, he obtained in 1880 the services of an experienced collector, David Baldwin, of Farmington, New Mexico, to make careful search for vertebrate remains in that formation. Baldwin collected with great success at intervals for several years, evidently finding the first Puerco fossils in the vicinity of Nacimiento and northward where the formation was known to Cope. More than ninety species of fossil mammals were sent from the Puerco which were described by Cope between 1881 and 1888 in numerous papers presented to the American Philosophical Society, Philadelphia Academy of Science, and the *American Naturalist*. These papers were devoted exclusively to descriptions of the fossils, with the exception of a brief note on "The Relation of the Puerco and Laramie Deposits" in the *American Geologist* for October, 1885, here quoted from as follows:

> Some writers having suspected the identity of the formations above named, and the consequence which follows, that the Puerco mammalian fauna was contemporary with the dinosaurian fauna of the Laramie age, the following observations on their stratigraphic relations are now given. They are derived from the

notes of several years' residence and exploration by my correspondent, David Baldwin, which connect those made by myself in New Mexico in 1874, published in the Wheeler Survey report, with those made by Holmes and Endlich in 1878 in Colorado, and published in the Hayden Survey report.

At the locality where best developed, the Puerco beds have a thickness of about 850 feet, and contain Mammalia to the base (see *Naturalist* for April and May, 1885). The Laramie beds succeed downward, conformably it is thought by Mr. Baldwin, and have a thickness of 2,000 feet at Animas City, New Mexico. They rest on Fox Hills marine Cretaceous of less thickness. A few fossils sent from time to time by Mr. Baldwin identify the Laramie. This is especially done by the teeth of the dinosaurian genus *Dysganus* Cope, which is restricted to the Laramie formation everywhere. Also by the presence of the genera *Laelaps* and *Diclonius*, which in like manner do not extend upward into the Puerco beds. . . . .

It is thus evident that the Puerco formation is quite distinct from the Laramie, although it is possible that it may be proper to associate it with the Laramie in the post-Cretaceous series. When the Cretaceous mammalian fauna comes to be known, it will be very apt to agree with the Puerco in its leading features. These are the absence of Perissodactyla and of Rodentia, and of course of mammalian orders not found below the Miocenes; and in the constitution of the mammalian fauna by Condylarthra, Bunotheria and Marsupialia exclusively. The post-Cretaceous series as a whole may be ultimately distinguished from the Tertiary by these peculiarities, together with the presence of the reptilian genus *Champsosaurus.*[21]

Concerning the taxonomy of the original Puerco, Cope was at first inclined to place the beds in the Eocene because of their apparent conformability at the top with beds known to be of that age. He freely referred to the "Puerco Eocene" in his earlier papers but in 1885 receded from this opinion and, on the basis of the Mesozoic affinities of the fauna, placed the Puerco in what C. A. White had proposed to call the post-Cretaceous. This term has been used more or less to the present time as signifying a zone between the known Mesozoic and Cenozoic eras. But it is evident that Cope considered the Puerco fauna more closely related to the Cretaceous than to the Tertiary faunas as indicated in the following quotation from the *American Naturalist:*

The fauna of this horizon is well distinguished from that of the Laramie in the absence of the numerous Dinosauria of the latter, and the presence of numerous Placental Mammalia in the former. On these grounds I at first referred the formation to the Cenozoic series, but further reflection induced me to place it as now arranged. The reason is as follows: Although Placental Mammalia are not now known otherwise from Mesozoic beds, the other forms of the Puerco are especially Mesozoic in character. Such are the Choristodere Reptilia and

the Multituberculate Marsupialia, neither of which occur above, while both occur below the Puerco, the Multituberculata down to the Trias inclusive. Then the Placentialia are entirely peculiar in the absence of the Diplarthra and of the Rodentia, orders always found in the Cenozoic beds. Then the characters of the Condylarthra and Amblypoda and many of the Creodonta, which represent Tertiary types, are so peculiar that we are led to suspect that when the Cretacic Mammalia are fully known they cannot differ very widely from those of the Puerco.

But one area of this formation is definitely known; that is in Northwestern New Mexico and Southwestern Colorado. It consists of sandstones and soapy marls, and has a thickness of 850 feet. It is immediately overlaid by the Wasatch Eocene, and rests on the Laramie.[26]

In the writings of various paleontologists since the time of Cope, the Puerco has been placed provisionally in the lowermost Eocene, as will be referred to in further paragraphs.

The statement has been made in geologic literature from time to to time that the Puerco formation occurs in northwest New Mexico and southwest Colorado; but no beds known to be Puerco in age have yet been found in Colorado. This mistake arose from the work of Endlich in the San Juan region in 1875.[7] This was the year after Cope had discovered the formation at the head of the Puerco River in New Mexico to which he gave the name Puerco, and an attempt was made to correlate the beds on the opposite side of the San Juan Basin in New Mexico and Colorado. Holmes was working the same year along the La Plata and San Juan valleys west of Endlich. Both of these geologists described certain strata in their respective districts as "The Puerco Marls," basing the correlations entirely on lithologic similarity and stratigraphic position. It may be said in this connection that the term "marl," applied by Cope and others to these soft argillaceous and siliceous beds, was improper, since the term, though used loosely in the present day, necessarily implies strongly calcareous material.

At the time of the work of Endlich and Holmes and until the work of the writer in 1907,[70] it was not known that the Nacimiento group lies unconformably on the "Laramie" and is in turn overlain unconformably by younger formations. For this reason, it was naturally assumed by the geologists of that time that beds in the same basin lying next above the "Laramie" were Puerco in age. But the formation described by Endlich in Colorado[7] as Puerco is the Animas

formation described and named by Cross in 1892.[34] It is probable that the Puerco of Endlich included some of the lower members of the Wasatch which was determined in 1909 by J. W. Gidley and the writer to lie next above the Animas formation in this portion of the basin. The beds described by Holmes[8] as Puerco in his Pinyon Mesa section, about six miles north of the San Juan River and just west of the La Plata River in New Mexico, may be either Puerco or younger in age. He characterizes the formation as consisting of "soft sand, clays, and marls, highly colored with reds, yellows, and purples, growing gray below and containing masses of soft sandstone." This description agrees more closely with the Canyon Largo series of Newberry[1] than with the Puerco. Holmes correlates Newberry's Canyon Largo series with the Wasatch, which is probably correct, since the beds occupy the innermost portion of the San Juan Basin and could not well be older than Wasatch even though Newberry referred the whole series to the Cretaceous.

Besides the collections of David Baldwin made during the years 1881 to 1888 no contributions were made to the Puerco fauna until the year 1892. Baldwin died at his home in Farmington, New Mexico, several years ago, and thus was lost to science a valuable collector and with him much information never placed on record relative to the geographic locations of many fossil-bearing districts. His original collections which were described in numerous papers by Cope were purchased in 1895 by the American Museum of Natural History in New York City.

In 1892 and 1896 the American Museum of Natural History sent expeditions into the San Juan Basin for the purpose of further study of problems connected with the Puerco fauna. This work was under the direction of Dr. J. L. Wortman. As a result of these expeditions, a large amount of new material was obtained.

Some time after the first season's collecting by Wortman in 1892 a paper was written by Professor H. F. Osborn and Mr. Charles Earle entitled "Fossil Mammals of the Puerco Beds."[37] In this paper they quote the following field notes from Wortman:

> The thickness of the beds is roughly estimated at 800 to 1,000 feet, and as far as can be observed they lie conformably upon the Laramie. At no place examined by us can fossils be said to be abundant, but on the contrary most of the exposures are entirely barren. For convenience they are divided into Upper

and Lower Beds, but this scarcely gives an adequate idea of the occurrence of the fossils, for the reason that it is only the extreme upper and lower strata that are productive; the great intermediate part we found to be singularly barren.

The lower fossil-bearing strata occur in two layers, the lowermost of which lies with ten or fifteen feet of the base of the formation. This is succeeded after an interval of about thirty feet by a second stratum in which fossils are found, and this appeared to be by far the richer of the two. Both of these strata are of red clay, and at no place did we find them more than a few feet in thickness.

The lower horizon we found exposed in two places, viz.: the head of the Coal Creek or Pina Verta Cañon, and some of the upper tributaries of the Chaco Cañon. It is especially and sharply distinguished by the occurrence of the remains of *Polymastodon*, which appear to be entirely absent from the upper horizon.

Fossils are much more abundant in the upper strata, and wherever a good exposure was found their occurrence could be more confidently looked for. The genera *Chirox* and *Pantolambda* appear to belong exclusively to the upper beds. Owing to the widely separated localities and the general scarcity of fossils, it is at present impossible to say whether it is one or several layers that produce the fossils from these upper beds. It is my opinion, however, that there are several layers, and that their vertical range is somewhat greater than that of the lower horizon. The principal localities of the upper strata are as follows: head of Cañon Gallego, Cañon Blanco, Cañon Escavada, and head of Cañon Chaco.

It will be noted that near the beginning of the above quotation Wortman states that the Puerco beds "as far as can be observed lie conformably upon the Laramie." This statement is somewhat qualified perhaps, due to the uncertainty which necessarily arises from a study of formation contacts in undisturbed, unconsolidated deposits; it is especially difficult to recognize an unconformity in badland topography in the absence of abundant fossils and especially so without detailed, continuous mapping.

Wortman states that the two lower fossil zones lying within fifty feet of the base of the Puerco are characterized by the remains of *Polymastodon*, whereas the fossil zone near the top contains *Chirox* and *Pantolambda* which do not occur in the lower beds. In fact the faunas of the upper and lower beds of the original Puerco were found to be entirely distinct, which later led to the substitution of the name Torrejon formation for the upper strata and the restriction of the name Puerco formation to the lower beds.

HISTORY OF THE TORREJON

The possibility of distinction between the faunas of the upper and lower beds of the original Puerco had been noted by Cope. In his paper on the "Synopsis of the Vertebrate Fauna of the Puerco Series"[29] in 1888 he stated that the information at that time available indicated some faunal difference between the lower and upper beds. In bearing out this view he gave a list of twenty species peculiar to the lower beds, leaving to research to determine whether or not they occur also in the upper beds.

After the field expeditions of the American Museum of Natural History in 1892 and 1896, a systematic revision of the fauna from Cope's Puerco was taken up by Dr. W. D. Matthew, of that organization. In his paper of 1897 entitled "A Revision of the Puerco Fauna"[44] he emphasized the absolute distinctness in the faunas of the upper and lower beds, stating that they contain not a single species in common and that not a genus passes through without serious modifications of at least subgeneric value. The faunas were found to be as different as any other two successive Eocene formations, and it became necessary to adopt a new name to designate one of the two. It was then that Dr. Wortman proposed the name Torrejon formation for the upper beds, retaining the name Puerco for the lower. The name Torrejon was taken from the arroyo of that name in the type-locality. It has since been freely used and is firmly fixed in literature.

In 1901 Mr. Earl Douglass discovered Torrejon fossil vertebrates in Montana,[52] a fuller reference to which will be given under the head of "Correlations." With the exception of the one locality in Montana, no fossils have been found elsewhere in the United States corresponding to either of these unique faunas of the Nacimiento group of the San Juan Basin in New Mexico.

NAMING OF THE NACIMIENTO

In view of the fact that the Puerco was restricted to the lower formation when the name Torrejon was proposed, and since it is very necessary to adopt a group name in order to properly discuss the relationship of the two formations, the writer proposes the name Nacimiento group for the two formations used collectively. The rela-

tion of the group to the two formations here discussed is shown as follows:

Nacimiento group { Torrejon formation / Unconformity (?) / Puerco formation

This name is taken from the town by that name in the type-locality at the foot of the Nacimiento Mountains. Here Cope mentions the importance of the "Puerco," which he used to include everything between the "Laramie" and the Wasatch in this region.

GEOLOGY OF THE TYPE-LOCALITY

The following observations and conclusions, together with the map, are based on the writer's field work in the summer of 1907 under the supervision of Mr. M. R. Campbell. In the preparation of the map and securing of geologic notes, valuable assistance was received from Mr. William J. Reed (deceased) and Mr. Albert L. Beekly.

The results of this work were chiefly of value in that a map was prepared of the region westward from the Sierra Nacimiento and on this the geology was imposed. The unconformable relationship of the Nacimiento group was noted for the first time and something was learned of the physiographic record of the district in the late Cretaceous and early Tertiary. Unfortunately, the advantage was not at hand of having paleontologic determinations in the field in order to know what formations were being dealt with at that time. For instance, no distinction could be made in the lithologic character of the upper and lower beds of the Nacimiento group, the result being that the Puerco and Torrejon formations were not mapped separately. At the time of the field work, the writer had not had occasion to be familiar with the literature on the Puerco, Torrejon, and Wasatch of this field, and did not know the stratigraphic position at which fossil vertebrates had previously been found. The results in paleontologic collecting were, however, all that could be expected under the circumstances and were sufficient to make possible definite correlations.

The region under discussion is one of little culture and sparse population. Gallina is a small Mexican settlement of about 100 people, located at the point where Gallina River emerges from the Sierra Nacimiento. About 14½ miles south-southwest is the old

Mexican town of Nacimiento, known to the postal officials as Cuba. This village contains about 200 inhabitants, and is located in a small fertile valley at the foot of San Pedro Mountain, near the point where Nacimiento Creek joins Rio Puerco. La Jara, Copper City, and Señorito are settlements of less importance. About thirty-four miles south of west from Cuba is Raton Spring, where there are two Mexican stores and a few dwelling-houses. Raton Spring is known also as Pueblo Pintado, a name formerly applied to the Aztec ruins, which are still evident at this place. The spring itself is a deep pool of some-

FIG. 2.—Puerco formation, ten miles west of south of Nacimiento, New Mexico

what alkaline water, which flows as a mere seep. At Ensina Spring, between Cuba and Raton, eleven miles north of east from Raton there are some Indian stone huts, but the spring is known as a watering-place for miles over the surrounding desert country. The water issues from beneath a massive sandstone, and the flow in August, 1907, was about one gallon per minute. These are the only localities worthy of individual mention here, but there are numerous Mexican ranches along the west foot of the Sierra Nacimiento between Gallina and Cuba.

On the west the Sierra Nacimiento presents a bold front, and along its slopes the sedimentary rocks are steeply inclined and

form hog-backs. At some places the slopes are extensively covered by bowlders and wash, principally granite and granite porphyry from the mountain mass. The broad plateau country, stretching westward to San Juan River, is a dry, barren expanse of highly colored mesas and badlands, known as the Nacimiento Desert.

The following generalized section presents the stratigraphic

FIG. 3.—Silicified stump in Puerco formation, near Encina Spring, New Mexico

relationship of the Nacimiento group in the region of the Puerco River:

GENERALIZED SECTION OF ROCKS IN THE PUERCO REGION

System	Series	Group or Formation	Thickness in Feet
Quaternary	Pleistocene	Recent terraces, etc.	0–50
Tertiary	Eocene	Wasatch formation (Unconformity)	1,000
		Nacimiento group (Unconformity): Torrejon formation	275
		Nacimiento group (Unconformity): (Unconformity ?)	
		Nacimiento group (Unconformity): Puerco formation	560
Cretaceous	Upper Cretaceous	"Laramie" formation	900
		Lewis shale	500
		Mesaverde formation	400
		Mancos shale	1,000
		Dakota sandstone	300

The character of individual strata composing the two formations of the Nacimiento group may be gathered from the following section along the west side of the Puerco River below Nacimiento:

SECTION OF NACIMIENTO GROUP ALONG PUERCO RIVER SOUTH AND WEST OF NACIMIENTO

		Thickness in Feet
(Wasatch formation)		
(Unconformity)		
Torrejon	Shale, variegated	20
	Sandstone, brown	3
	Shale, gray	15
	Sandstone, gray	3
	Shale, gray and soft sandstone	40
	Sandstone, massive, tan-colored	15
	Shale, yellowish	15
	Sandstone, massive, soft, coarse, tan-colored	120
	Shale, gray	20
	Sandstone, massive, soft, tan-colored	30
(Unconformity)	Thickness of Torrejon formation	276
Puerco	Shale and soft sandstone	30
	Shale, dark, carbonaceous	10
	Shale, gray	10
	Sandstone, massive, yellowish, lenticular	10
	Shale, variegated	25
	Shale, dark carbonaceous	4
	Shale, chiefly yellowish	80
	Sandstone, massive, brown, lenticular	10
	Shale, variegated and soft, gray sandstone	200
	Sandstone, massive, coarse-grained, brown	40
	Shale, gray and soft sandstone	45
	Shale, very dark, local coal streaks	4
	Shale and soft sandstone of gray and tan colors	90
(Unconformity)	Thickness of Puerco formation	558
(Lewis shale)	Thickness of Nacimiento group	834

The section given above may be taken as typical for the beds of the Nacimiento group in the type-locality. The total thickness of either the Puerco or Torrejon is variable owing to the unconformities that limit each of these formations at the top. This limitation in thickness is brought about by erosion and removal of rocks during the time-interval after the close of each formation.

The Puerco and Torrejon formations are not sufficiently contrasted lithologically to permit of their being readily separated at all points without fossil evidence. Along the Puerco River, where erosion has removed the greatest amount of material the stratigraphic succession is more clearly exposed than at any other point within the area. Here the entire group, with a total thickness of about 835 feet, forms prominent escarpments, mesas, and badlands along a wide belt between the outcrops of the "Laramie" and the Wasatch.

FIG. 4.—Torrejon formation, eight miles northeast of Encina Spring, New Mexico, showing one of the natural monuments from which the Arroyo Torrejon takes its name.

In this vicinity, the Puerco formation is characterized to some degree by the presence of dark to black layers of carbonaceous shale. At a point about three miles north of east of Nacimiento and at about the same horizon, near the base of the formation eleven miles west of south of the same town, there are local thin lenses of coal in the Puerco formation. In the Torrejon formation northeast of Encina Spring, where fossil mammals were found, thus enabling positive identification of those beds, there are occasional, lenticular layers of dark

carbonaceous shale very similar to the dark layers in the underlying Puerco; but on the Puerco River the carbonaceous layers are confined to the Puerco formation almost entirely.

Both the formations of the Nacimiento group consist essentially of variegated clay shale, arenaceous shale, and soft, coarse-grained sandstone of white, gray, and tan colors. Such beds are of that consistency necessary to the development of badland topography, with the exception of local, siliceous sandstones hard enough to form mesas or dip slopes through which intermittent streams cut canyons into the underlying shale. The latter is more particularly the type of topography in the vicinity of Nacimiento. The softer sandstones which commonly alternate with the arenaceous and clay shale usually weather to soft incoherent sand at the outcrop. These beds have been said to consist in part of unconsolidated sand but the writer has found the term applicable only to weathered exposures; for in every case the sand is solid at a short distance from the surface.

There are local conglomerate layers in both the Puerco and Torrejon but they are of minor importance and exceptional. No one member of either of the formations is a true conglomerate such as the basal conglomerate of the Wasatch formation. However, occasional lenses of small quartz and chert pebbles are to be seen in the more massive, coarse-grained, siliceous sandstones.

The basal sandstone of the Wasatch is strongly conglomeratic, consisting of pebbles averaging the size of an egg and of varied composition; the pebbles consist of quartz and chert, of red, black, brown, and white colors, and various crystalline rocks. The matrix is composed chiefly of coarse, brown quartz grains. This sandstone is a prominent horizon-marker over a wide area on the south and east sides of the San Juan Basin. On the north side of the basin, in southwest Colorado, where the Wasatch rests on the Animas formation, this conglomerate member is absent.

With the exception of the conglomerate above mentioned the formations of the Nacimiento group are lithologically distinguished only in a slight degree from the overlying Wasatch. The Wasatch contains a larger percentage of highly colored shales and softer sandstones than the Nacimiento, but otherwise the composition is not materially different. The contrast of the Nacimiento group with the "Laramie"

of this basin is more marked since the latter consists largely of massive brown sandstones alternating with drab, clay, and arenaceous shale together with local carbonaceous shale and coal beds.

The structure in the area under discussion, with the exception of unconformable relationships in strata, is such as is common around the margins of most of the minor basins in the Rocky Mountain province. Steeply inclined strata limit the older sedimentary rocks along the boundary of the Nacimiento Mountains, the dips decreasing westward toward the interior of the San Juan Basin. (See

FIG. 5.—Upper escarpment of Nacimiento group, four miles southwest of Nacimiento, New Mexico.

sketch map, Fig. 1.) Near the mountains, this inclination varies from 35° north of Gallina to more than 90° at Copper City and northward. In the latter district, the fold is overturned and dips 70° eastward toward the mountains. All the sedimentary formations above the Jurassic have this inclination with the exception of the Wasatch. About ten miles northwest of Gallina the Wasatch has an inclination of about 10° west of south as mentioned by Cope[5] and verified by the writer. The dip in that vicinity is apparently local and is of more recent date than any uplift in the Nacimiento Mountains as shown by the fact that the Wasatch beds rest nearly horizontally against the crystalline rocks of those mountains between Gallina and Nacimiento.

Along the Arroyo Torrejon, the Cretaceous and Tertiary formations are very slightly disturbed; the dips in this region are probably initial slopes with the exception of local variations produced by settling of the strata; the latter are noticeable in the Torrejon beds on the east fork of the Arroyo Torrejon near the Escavada road.

The Nacimiento group is limited by very evident unconformities at the top and bottom as shown on the accompanying map. The more evident of these two unconformities is the one at the top, or at the base of the Wasatch formation. Between Gallina and Nacimiento the Wasatch covers the outcrops of sedimentary rocks, including the Nacimiento, "Laramie," Lewis, Mesaverde, Mancos, Dakota, and older formations. Four miles northeast of Nacimiento, where the Wasatch covers the upturned edges of older rocks, and from there northward along the foot of the mountains, the unconformable relationships are strikingly shown. This overlap of the Wasatch on older beds is equally evident four miles northwest of Gallina, where the soft, variegated shales swing across nearly to the Mesaverde hog-back. This unconformity at the base of the Wasatch is not easily recognized away from the mountains. The contact with the underlying formation of the Nacimiento group on the Arroyo Torrejon would not ordinarily be considered unconformable; for there is no discordance in dip in that section and there is no contrast in either composition or color of the sediments on either side of the contact. The variegated shale and soft sandstone of the Torrejon and Wasatch on respective sides of the unconformity are very similar. These facts, together with the variability in color and lenticular character of deposits in each of the formations, make this unconformity very difficult of detection except where the stratigraphic break is recorded in the dynamic structure. The same holds true for the unconformity at the base of the Puerco.

The unconformity at the base of the Puerco formation is evident at the point eleven miles southwest of Nacimiento, where the "Laramie" sandstone, shale, and accompanying coal beds appear from beneath the Puerco striking nearly at right angles with it. Westward from this locality, where the outcrops are nearly parallel and there is no inconsistency in direction of dip, the unconformity is not so easily noted.

The hiatus between the "Laramie" and the Puerco apparently does not represent so great a time-interval as that between the Torrejon and the Wasatch. The indications are that the unconformity at the base of the Puerco is in part one of overlap. The angularity is slight between it and the underlying "Laramie" and Lewis shale. However, the direction of strike at the point of overlap is not the same as in the lower formation, which fact probably indicates a slight folding of the Cretaceous rocks and subsequent erosion previous to the deposition of the Puerco formation. On the other hand, the

FIG. 6.—Shale of the Nacimiento group, three miles northeast of Nacimiento, New Mexico. Tilted to vertical by uplift of the Nacimiento Mountains.

break at the base of the Wasatch is represented by a very strong angular unconformity indicating a long period of erosion previous to its deposition, after the close of the Torrejon.

The unconformity between the Puerco and Torrejon formations cannot be noted in the field except on fossil evidence. It is highly probable that it is one essentially of overlap with very little stratigraphic break. The two formations are so closely similar in lithologic character that it is difficult to distinguish one from the other without the assistance of fossils. For this reason, the two could not be indicated separately in the brief season spent in the preparation of data for the accompanying map. However, the base of the Torrejon is

known at certain points and the inconstant thickness of the interval between this horizon and the base of the Puerco indicates the unconformable relationships between the two formations. For instance, on the Rio Puerco and at other points where the full section of the Nacimiento group is represented, the Torrejon formation is more than 500 feet stratigraphically above the base of the Puerco. From the Rio Puerco, where the full section of the group is present, the base of the Puerco formation was traced westward very definitely to the Arroyo Torrejon. In the latter district some of the upper members of the Puerco are notably absent and the Torrejon fossil mammals were secured at a little over 200 feet above the base of the Puerco, thus indicating an unconformity at that point unless a very notable thinning takes place in only the upper member of the Puerco. Since the members in the lower portion of the Puerco are persistent across the area and since the vertical distance between the base of the Puerco and the base of the Torrejon is scarcely sufficient to represent the great time-interval indicated by the evolution of the Torrejon fauna, it seems highly probable that the Torrejon is unconformable here. The stratigraphic section as prepared on the east fork of the Arroyo Torrejon is given below:

SECTION OF THE NACIMIENTO GROUP ON THE EAST FORK OF ARROYO TORREJON, FOUR MILES EAST OF THE FARMINGTON ROAD

		Thickness in Feet	
(Wasatch, massive, conglomeratic sandstone at base)			
(Unconformity)			
Torrejon	Shale, drab and gray	14	
	Shale, dark, carbonaceous and thin sandstone	20	
	Sandstone, soft, gray and reddish shale	16	
	Shale, black, yellow, drab, and gray	35	
	Sandstone, soft, tan-colored	20	
	Shale, gray, strongly arenaceous (fossil mammals)	35	
(Unconformity?)	Thickness of formation		140
Puerco	Shale and soft sandstone	100	
	Sandstone, massive, coarse-grained, tan-colored	30	
	Shale, red, purple, drab, and white	30	
	Shale, sandy, gray, dark, and yellowish	50	
(Unconformity)	Thickness of formation		210
"Laramie," sandstone, massive, brown	Thickness of group		350

The third member above the base of the Puerco in the above section is a very persistent horizon-marker and corresponds to the fourth member above the base of the Puerco in the section previously given along the Puerco River; this member was traced continuously from the Nacimiento Mountains to beyond the Arroyo Torrejon.

The sedimentary record as preserved in the strata of the Nacimiento group is capable of slight variance of interpretation in respect

FIG. 7.—Shale of the Nacimiento group, three miles northeast of Nacimiento, New Mexico. Short distance west of the preceding view.

to origin. It is evident, however, that they were deposited in fresh water as shown by both the lithologic composition and the fossils. The beds may be largely the result of accumulation of sediment on the floor of an extensive fresh-water lake with alternate flooding and withdrawal of water, or they may have resulted chiefly from confluent alluvial fans along broad streams; or more probably the physiography involved a combination of the two conditions.

There is a notable absence of chemical deposits in the formations

under discussion except those resulting from secondary deposition or weathering. There are occasional concretions of barite observed by the writer in the Torrejon shale ten miles northeast of Encina Spring, which may be nearly contemporaneous with the rocks which inclose them. These are rough, irregular-shaped, often discoidal aggregations of impure barium sulphate; they lie imbedded in clay shale with which they harmonize closely in color, being usually dark gray with a slightly bluish tinge. It is quite possible that they represent the segregation of this slightly soluble salt at the time of deposition or while the shale was in a semiplastic state. Neither the Puerco nor Torrejon, so far as known, contains any primary deposits of salt, gypsum, or limestone; rarely there are present thin lenses of dark-colored limonite.

The beds of the Nacimiento group show evidences of the existence of currents from time to time during their deposition. Thin layers of small quartz pebbles and cross-bedding are not uncommon. The sudden termination along the bedding of massive sandstones is quite common and in the absence of faults can scarcely be accounted for except by the effects of stream-channels. The presence of smooth, globular forms of siliceous sandstone within sandstone of a similar matrix may be accounted for by either concretionary forces or by the action of currents. The variegated shale layers common to the upper beds and the overlying Wasatch formation probably represent varying degrees of oxidation at or near the surface during deposition.

It is the writer's opinion that the materials of the Nacimiento group in this region were transported by broad, shallow streams and laid down in deltas, lagoons, and shallow fresh-water lakes over a broad peneplaned surface. At the close of the Cretaceous, this portion of the continent was possibly slightly above sea-level, the elevation having been gradual from the time of marine deposition of the Lewis shale on through a time of brackish and fresh-water accumulation to land conditions at the close of the "Laramie." There was then a period of widespread orogenic movement, mountain growth, and attendant structure, accompanied and followed by erosion and accumulation of local, fresh-water sediments; at this time the formations of the Shoshone group, including the Arapahoe and Denver formations, of the Denver Basin, and the Animas formation of the

San Juan Basin were deposited. The uplift in the San Juan Mountains of southwestern Colorado at the close of the "Laramie" folded the Cretaceous sediments steeply along its flanks, but at some distance from them the sedimentary rocks were only slightly disturbed and possibly at no great elevation above tide. While local deposition was in process at this time in certain regions near the mountains, the elevated sedimentaries over other, perhaps extensive, areas were

FIG. 8.—Shale in the Wasatch formation, six miles southwest of Gallina, New Mexico, similar in appearance to the Nacimiento, but usually more highly variegated.

being reduced to base-level. By the beginning of Puerco time an extensive gently sloping plane had been produced over which broad streams flowed quietly to the sea, depositing sediment in shallow lakes and lagoons along their courses and at times shifting in position or overflowing and commingling with each other. Such a theory seems to explain the nature of the deposits as well as the conditions suitable to the fauna. In order to account for the thickness of the sediments deposited in this manner it seems necessary to assume that a slow submergence of the land kept equal pace with deposition.

The Nacimiento beds probably once extended far beyond the present confines of the Eocene in the San Juan Basin; possibly southward toward the Gulf of Mexico and westward into Arizona and Utah. The beds are confined to this basin at present because it owes its origin to structure which was produced certainly in part, and perhaps largely, after the close of Nacimiento time. Subsequent erosion has removed the formations of this group probably over extensive bordering regions while within the basin they are preserved by a thick covering of Wasatch. The Nacimiento Mountains, which limit the basin on the east, were surely elevated after the close of Nacimiento time, since the strata of that group are tilted at high angles and even overturned along its flanks. These mountains are of laccolithic origin and both the Puerco and Torrejon undoubtedly at one time continued beyond them.

FOSSILS

The fossils thus far found in the beds of the Nacimiento group by Baldwin and subsequent collectors are chiefly vertebrates and in a large measure representatives of the Mammalia. There are several genera and species among the Reptilia and fragments of bones of undetermined specimens of Aves. Of the Mollusca, four fresh-water forms from the Puerco, near the town of Nacimiento, were sent to Cope and described by Dr. C. A. White in 1886.[23] Among these forms, White doubtfully determined one species as *Unio rectoides* which he had found in the base of the Wasatch near Wales, Utah. Unfortunately the Nacimiento has furnished no fossil leaves, the only indications of flora being found in the form of silicified limbs, trunks, and stumps of dicotyledonous and palm trees.

The following remarks relative to the fossil mammals of the Nacimiento group are quoted from Professor H. F. Osborn:[65]

POLYMASTODON ZONE (PUERCO FORMATION)

Small archaic mammals evolving from Cretaceous, Jurassic, and Triassic ancestors. Multituberculata, which originated in the Triassic, 3 families. Two orders of archaic ungulates—(1) Amblyopoda-Periptychidae, (2) Condylarthra-Phenacodontidae. Archaic Carnivora-Creodonta, 3 families: (1) Oxyclaenidae, (2) Mesonychidae-Triisodontinae, (3) Arctocyonidae (*Claenodon protogonoides*). Edentata-Taeniodonta, with enameled teeth, 2 families: (1) Stylinodontidae, (2) Conoryetidae.

SUMMARY OF GENERA AND SPECIES

	Genera	Species
Archaic Triassic mammals	3	5
Archaic Cretaceous mammals	15	24
Total archaic mammals	18	29
Modernized or distinctively Tertiary mammals	0	0

The Puerco is a fauna wholly of Mesozoic origin, and mostly destined to disappear; not a single representative or ancestor of any existing order of Tertiary mammals is certainly known. Cope's opinion that many of these mammals were ancestral to the modernized mammals lacks direct confirmation at present. Other paleontologists, however, are inclined to connect certain of the creodont families with the modern Carnivora. These and other ancestral connections may be demonstrated in the future.

Negatively, therefore, the Puerco is distinguished by the absence of primates, rodents, true carnivores, specialized insectivores, artiodactyls, perissodactyls, etc. This generalization has hardly less important bearings on paleogeography than on paleozoölogy.

PANTOLAMBDA ZONE (TORREJON FORMATION)

Like the Puerco this is almost exclusively a Mesozoic fauna, destined to become extinct during the Eocene. The known exceptions in surviving types are the pro-Carnivora-Miacidae, which first appear at this stage. Others will be discovered.

Mammals of larger size, mostly evolved from the Puerco mammals. Last survivors of the Multituberculata. Edentata-Taeniodonta of larger size. Of archaic Ungulata, 2 orders and 3 families: (1) Condylarthra-Phenacodontidae, (2) Amblypoda-Periptychidae, (3) Amblypoda-Pantolambdidae. Of the latter, *Pantolambda* is supposed to be ancestral to the Coryphodontidae of the Wasatch. Carnivora-Creodonta, 4 families: (1) Mesonychidae, (4) pro-Carnivora-Miacidae. The primate-like *Indrodon* and aberrant *Mixodectes* are of unknown relationships; they are possibly Insectivora.

SUMMARY OF GENERA AND SPECIES

	Genera	Species
Archaic Triassic stock	3	4
Archaic Cretaceous stock	21	36
Total archaic stock	24	40
Modernized Tertiary stock	1	1

LIST OF FOSSILS FOUND IN THE PUERCO AND TORREJON FORMATIONS

MAMMALIA*

Puerco Polymastodon zone 1. San Juan Basin, New Mexico		Torrejon Pantolambda zone 1. San Juan Basin, New Mexico 2. Fort Union formation (in part), Montana		
			1	2
MULTITUBERCULATA				
Plagiaulacidae				
Neoplagiaulax americanus Cope...	×	*Neoplagiaulax molestus* Cope...	×	
Catopsalis foliatus Cope.....	×	*Ptilodus mediaevus* Cope.....	×	
Polymastodon taoensis Cope.....	×	*Ptilodus trovessartianus* Cope...	×	
Polymastodon attenuatus Cope.....	×	*Ptilodus plicatus* Cope.....	×	
Polymastodon selenodus O. and E..	×	*Ptilodus montanus* Douglass....		×
		Ptilodus gracilis Gidley.....		×
		Polymastodon fissidens Cope....	?	
CREODONTA				
		Miacidae		
		Didymictis haydenianus Cope...	×	
		Arctocyonidae		
		Claenodon corrugatus (Cope)...	×	
(?)		*Claenodon ferox* (Cope).....	×	
		?Claenodon protogonioides (Cope).....	×	
		Mesonychidae		
		Dissacus navajovius Cope.....	×	
		Dissacus saurognathus Wortman	×	
		Triisodontidae		
Triisodon quivirensis Cope	×	*Sarcothraustes antiquus* Cope....	×	
Triisodon heilprinianus Cope.....	×	*Goniacodon levisanus* Cope.....	×	
Triisodon quadrianus Cope.....	×	*Microclaenodon assurgens* Cope..	×	
		Oxyclaenidae		
Oxyclaenus cuspidatus Cope.....	×	*Chriacus pelvidens* (Cope).....	×	
Oxyclaenus simplex (Cope).....	×	*Chriacus baldwini* Cope.....	×	
Loxolophus hyattianus (Cope).....	×	*Chriacus truncatus* Cope.....	×	
Loxolophus priscus (Cope).....	×	*Chriacus schlosserianus* Cope...	×	
Loxolophus attenuatus O. and E...	×	*Tricentes subtrigonus* (Cope)....	×	
Carcinodon filholianus (Cope).....	×	*Tricentes crassicollidens* Cope...	×	
Paradoxodon rutimeyeranus (Cope)	×	*Deltatherium fundaminis* Cope.	×	

* The arrangement of the list of mammals is that of Dr. W. D. Matthew. See bibliography, No. 65.

INSECTIVORA

?Hyopsodontidae

Mioclaenus turgidunculus Cope	×	*Mioclaenus turgidus* Cope	×
		Mioclaenus lemuroides Matthew	×
		Mioclaenus acolytus Cope	× ×
		Mioclaenus lydekkerianus Cope	×
		Mioclaenus inaequidens (Cope)	×
		?Protoselene opisthacus (Cope)	×

Incertae sedis

Oxyacodon apiculatus O. and E.	×		
Oxyacodon agapetillus (Cope)	×		

Pantolestidae

		Pentacodon inversus Cope	×

Mixodectidae

		Mixodectes pungens Cope	×
		Mixodectes crassiusculus (Cope)	×
		Indrodon malaris Cope	×

TAENIODONTA

Stylinodontidae

Wortmania otariidens Cope	×	*Psittacotherium multifragum* Cope	×

Conoryctidae

Onychodectes tisonensis Cope	×	*Conoryctes comma* Cope	×
Onychodectes rarus O. and E.	×		

CONDYLARTHRA

Phenacodontidae

?Protogonodon pentacus Cope	×	*Tetraclaenodon puercensis* (Cope)	× ×
?Protogonodon stenognathus Matthew	×	*Tetraclaenodon minor* (Matthew)	× ×

AMBLYPODA

Periptychidae

Periptychus coarctatus Cope	×	*Periptychus carinidens* Cope	×
Ectoconus ditrigonus (Cope)	×	*Periptychus rhabdodon* (Cope)	×
Conacodon entoconus (Cope)	×	*Haploconus lineatus* Cope	×
Conacodon cophater (Cope)	×	*Haploconus corniculatus* Cope	×
Anisonchus gillianus Cope	×	*Anisonchus sectorius* Cope	×
Hemithlaeus kowalevskianus Cope	×		

Pantolambdidae

		Pantolambda bathmodon Cope	×
		Pantolambda cavirictus Cope	× ×

The following fossils other than mammalia have been found in beds of the Nacimiento group in New Mexico:

REPTILIA

CROCODILIA

Several new undescribed species

TESTUDINATA

Conchochelys admirabilis Hay (Nacimiento)
Plastomenus acupictus Hay (Torrejon)
Aspideretes singularis Hay (Torrejon)
Platypeltis antiqua Hay (Torrejon)
Plastomenus? communis Cope
Chelydra crassa Cope
Dermatemys sp.
Compsemys sp.
Emys sp.

RHYNCOCEPHALIA

Champsosaurus australis Cope
Champsosaurus puercensis Cope
Champsosaurus saponensis Cope

OPHIDIA

Helagras prisciformis Cope

AVES

Fragments of bones of undetermined species

MOLLUSCA

Helix nacimientensis
Helix adipis
Pupa leidyi (?)
Unio rectoides (?)

FLORA

Wood of dicotyledonous and palm trees, undetermined

The fossil mammal teeth shown in Fig. 9 were collected by the writer in 1907 from the Torrejon formation eight miles northeast of Encina Spring, New Mexico (see Plate I). These fossils are in the hands of Mr. James W. Gidley, custodian of fossil mammals in the National Museum. He furnishes the following identifications of them which are subject to correction. There are new genera and species represented which will be described fully in a forthcoming paper by Mr. Gidley.

FIG. c.—Fossil mammal teeth from the Torrejon formation, magnified 3 diameters, except No. c, which is 4 diameters.

No. 1. *Chriacus plevidens* (Cope), last right lower molar, crown view. Accession No. 5713.

No. 2. Same as No. 1 (side view).

No. 3. *Periptychus carnidens*, left lower molar, m_2, crown view. Accession No. 5707.

No. 4. *Periptychus carnidens*, right lower premolar, ? p_3, crown view. Same individual as No. 3.

No. 5. *Euprotogonia puercensis*, last right upper molar, crown view. Accession No. 5710.

No. 6. *Insectivor*, new genus and species, right lower molar, ? m_2, side view. Accession No. 5715.

No. 7. Same as No. 6, crown view.

No. 8. *Olbodotes ? copei*, second upper molar of left side, crown view. Accession No. 5714.

No. 9. *Oxyclaenus* sp., second upper molar of left side crown view. Four times natural size.

No. 10. *Tricentes subtrigonus*, second upper molar of right side in fragment of jaw, crown view. Accession No. 5709.

No. 11. *Miacidae*, genus and species new, second upper molar of right side, crown view. Accession No. 5712.

CORRELATIONS

With the exception of a small area in Montana where Torrejon fossils have been found, neither of the faunas of the Nacimiento group is known in North America outside of the one limited region in the San Juan Basin of northwestern New Mexico.

The beds in Montana which contain the Torrejon fossils were discovered by Mr. Earl Douglass in 1901.[52] The first fossils were found near Fish Creek in Sweetgrass County, T. 6 N., R. 16 E., in beds of Fort Union age. A collection of leaves from a sandstone overlying the shale containing Torrejon vertebrates was sent to Dr. F. H. Knowlton who pronounced the species all Fort Union beyond a doubt. In 1908 and 1909 collections for the U.S. National Museum were made in this region by Messrs. A. C. Silberling and J. W. Gidley. All who have worked in the district agree that the fossils are in the Fort Union and all who have studied the fauna, including Scott, Matthew, Gidley, Farr, and Douglass, agree that the fossils are Torrejon. In that region beneath the Fort Union, containing the fossil mammals, is the Lance formation or "Ceratops beds." This formation contains dinosaurs and is Cretaceous in age, unless perchance dinosaurs lived into Tertiary time as the flora seems to

indicate. The evidence as to the age of these beds is conflicting when viewed from different paleontological standpoints, and has led to an interesting discussion by Stanton[69] and Knowlton.[68] But so far no fossils of the lower formation of the Nacimiento group, or Puerco, have been found in Montana. It is quite possible that they may be discovered later either in lower beds of the Fort Union or in the underlying Lance formation.

There is one locality on the south side of the San Juan Basin, namely at Ojo Alamo (see Plate II), where the writer obtained dinosaurs from beds unconformably above the "Laramie" and below the Wasatch. Mr. C. W. Gilmore of the U.S. National Museum reports that they appear to represent a typical fauna of the "Ceratops beds." The beds at Ojo Alamo have been searched in vain for fossil mammals and have furnished several new species of fossil turtles, but the fact remains that so far they have not been correlated with any other formation of that basin. They are very similar in appearance to the beds of the Nacimiento group, are only a short distance west of the Puerco region, and occupy the interval between the "Laramie" and Wasatch. Their definite relation to the Nacimiento group must be left for future elucidation.

There are two foreign countries where faunas closely related to those of the Nacimiento group have been found, one in Europe, the other in South America.

The Thanetien, or Cernaysien, of France, corresponds broadly with the Puerco and Torrejon.[32, 48, 65] As pointed out by Osborn,[65] the fauna of the "Conglomerat de Cernay" near Rheims shows a homotaxis with that of the Torrejon by similar stages of evolution in the representatives of three families, namely, (1) Plagiaulacidae, (2) Arctocyonidae, and (3) Mesonychidae-Triisodontidae. Other identifications are very uncertain.[32] Professor Charles Depéret, of the University of Lyons, correlates the beds of Cernay with those near La Fère, Rilly, Châlons-sur-Vesle, in France, and the Erguelines in Belgium.

In South America, the basal Eocene or Notostylops beds of Patagonia contain fossil mammals similar to those of the Puerco formation,[65] thus probably indicating a contemporary or previous land connection between the two Americas.

SUMMARY

The beds comprising the Nacimiento group were discovered by Professor E. D. Cope[5] in 1874 on the head drainage of the Puerco River in the San Juan Basin, northwest New Mexico. In 1875, these beds were thought to have been identified on the opposite side of the basin in New Mexico by Dr. W. H. Holmes.[8] The same year Dr. F. M. Endlich[7] working in the San Juan Basin north of the New Mexico boundary line correlated with the Puerco a series of beds along the Animas River in southwest Colorado. These correlations of the Puerco by Holmes and Endlich were based entirely on lithologic resemblance and stratigraphic position. The beds spoken of by Holmes[8] in his Pinyon Mesa section may be either Puerco or younger, while the beds described by Endlich[7] and shown on Hayden's Preliminary Map of Central Colorado are now known by the writer to be identical in larger part with the Animas formation of Dr. Whitman Cross.[34]

The name Torrejon was proposed by Dr. J. L. Wortman in 1897[42] for those beds previously known as the upper part of the Puerco, but which contain species of fossil vertebrates totally different from those of the lower beds, subsequently known as Puerco proper. The discovery of the Torrejon fauna was due to Dr. Wortman's observations in the field in 1892[37] together with paleontologic records kept by the American Museum of Natural History.

The Puerco and Torrejon formations have not been identified over wide areas. All the fossils collected from these formations came from limited districts in northwest New Mexico until recent years. Neither of the two formations had been positively identified beyond this region, nor similar fossils found elsewhere, until 1901. That year Mr. Earl Douglass[52] discovered Torrejon vertebrates near Fish Creek of the Musselshell River, Montana. The U.S. National Museum has since made extensive collections of these fossils, but no typical Puerco fauna has yet been discovered in North America outside of the San Juan Basin in northwest New Mexico. As has already been set forth, the "Laramie" and the Nacimiento of the San Juan Basin were each followed by a stratigraphic break, involving a considerable erosion-interval and marked faunal change. An unconformity of less importance separates the two formations of

the Nacimiento group. Unfortunately, no flora has been discovered from either of these formations. The great break in the character of the fossil vertebrates in passing from one formation to the other, or to the underlying "Laramie" and overlying Wasatch, has long been a puzzle. The beds were thought by Cope to lie conformably on the "Laramie" and in turn to be overlain conformably by the Wasatch. This idea was borne out by later authors on the subject and collectors in the field. Not until the work of the writer in 1907, however, had there been any attempt at mapping the formations. It was in connection with tracing the formation boundaries and a study of the physiographic record that the unconformities became evident. Lithologically the Torrejon is not sufficiently distinct from the Puerco to permit of its being readily mapped in the field, the separation being made on fossil evidence.

In this paper the topography, structure, stratigraphy, and physiographic record of the Puerco district have been described for the first time with the exception of a brief reference by the writer in one of the bulletins of the U.S. Geological Survey.[70]

The faunas of the Nacimiento group are unique. The upper fauna, the Torrejon, is known in only one limited area of North America outside of the type-locality. This is east of the Crazy Mountains in Montana. The lower fauna, the Puerco, is not known to occur in America except in the San Juan Basin of New Mexico. Outside of North America, fossils closely related to those of the Nacimiento group have been found in certain districts of Europe and South America, the European localities being confined to France and Belgium, where fossil mammals are known in the early Eocene corresponding closely to those of the Torrejon formation, while fossil mammals more nearly related to those of the Puerco formation are found in Patagonia.

BIBLIOGRAPHY

1. NEWBERRY, J. S., 1859. "Report of the Exploring Expedition from Santa Fe, New Mexico, to Junction of Grand and Green Rivers of the Great Colorado of the West, under Command of Capt. J. N. Macomb," Geological report by Newberry, printed Washington Government Printing Office, 1876.
2. COPE, E. D., 1873. "On the Mutual Relations of the Cretaceous and Tertiary Formations of the West," *7th Annual Report*, U.S. Geological and Geographical Survey of the Territories, 431–44.

3. COPE, E. D., 1874. "Review of the Vertebrates of the Cretaceous Period Found West of the Mississippi River," *Bull. No. 2*, First Series U.S. Geological and Geographical Survey of the Territories, I, 5–48.
4. COPE, E. D., 1874. "Notes on the Eocene and Pliocene Lacustrine Formations of New Mexico, Including Descriptions of Certain New Species of Vertebrates," *Annual Report Chief of Engineers*, Part II, Appendix FF_3, 591–606.
5. COPE, E. D., 1875. "Report on the Geology of That Part of Northwestern New Mexico Examined during the Field Season of 1874," 981–1017, *Annual Report of the Chief of Engineers to the Secretary of War* for the year 1875, Part II, Appendix G1, chap. vi, "The Eocene Plateau," 1008–17.
6. COPE, E. D., 1875. "On Fossil Lemurs and Dogs," *Proc. Philadelphia Academy Natural Science*, XXVII, 255–56.
7. ENDLICH, F. M., 1875. "San Juan Region, Tertiary," *U.S. Geological and Geographical Survey of Colorado and Adjacent Territory;* Hayden, 189–90, chap. iv, 176–91.
8. HOLMES, W. H., 1875. "La Plata Valley," *ibid.*, Hayden, 247–48, chap. ii.
9. COPE, E. D., 1877. "Vertebrata," *U.S. Geographical Survey W. 100th Meridian*, Vol. IV, Part II, 13–19, Eocene Plateau same as in *Annual Report of Chief of Engineers*, Appendix G1, chap. vi, 1008–17.
10. COPE, E. D., 1881. "On Some Mammalia of the Lowest Eocene Beds of New Mexico," *Proc. Am. Philadelphia Society*, XIX, 484–95. Read before Society, September 17, 1881.
11. COPE, E. D., 1882. "The Tertiary Formations of the Central Region of the U.S.," *American Naturalist*, XVI, 177–95.
12. COPE, E. D., 1882. (1) "A New Form of Taeniodonta"; (2) "Some New Forms from the Puerco Eocene," *American Naturalist*, XVI (1882), 831–33.
13. COPE, E. D., 1882. "Synopsis of the Vertebrata of the Puerco Eocene Epoch," *Am. Phil. Soc. Proceedings*, XX (1882–83), 461–71. Read before Society, October 10, 1882.
14. COPE, E. D., 1882. "Contributions to the History of the Vertebrata of the Lower Eocene of Wyoming and New Mexico Made during 1881," *Proc. Am. Phil. Soc.*, XX, 139–94.
15. COPE, E. D., 1883. "On Some Fossils of the Puerco Formation," *Proc. Phila. Acad. Sci.* (1883), 168–70. Read July 3, 1883.
16. COPE, E. D., 1883. "First Addition to the Fauna of the Puerco Eocene," *Proc. Am. Phil. Soc.*, XX, 545–63.
17. COPE, E. D., 1883. "Second Addition to the Knowledge of the Puerco Epoch," *Proc. Am. Phil. Soc.*, XXI (1883–84), 309–24.
18. COPE, E. D., 1883. "The Ancestor of Coryphodon," *Am. Naturalist*, XVII (1883), 406–7.

19. COPE, E. D., 1884. "The Vertebrata of the Tertiary Formations of the West," *U.S. Geol. Survey of Territories*, F. V. Hayden in charge, III, 4–1009.
20. COPE, E. D., 1884. "The Creodonta," *Am. Naturalist*, XVIII, 255–67, 344–53, 478–85.
21. COPE, E. D., 1885. "The Relations of the Puerco and Laramie Deposits," *Am. Naturalist*, XIX, 985–86.
22. DUTTON, C. E., 1885. "Mt. Taylor and the Zuni Plateau," *U.S. Geological Survey, 6th Annual Report.*
23. WHITE, C. A., 1886. "On the Relation of the Laramie Molluscan Fauna to That of the Succeeding Fresh-Water Eocene and Other Groups," *Bull. U.S. Geol. Surv., No. 34* (1886).
24. COPE, E. D., 1887. "The Mesozoic and Cenozoic Realms of the Interior of North America," *Am. Naturalist*, XXI, 445–62.
25. COPE, E. D., 1887. (1) "Some New Taenidonta of the Puerco"; (2) "A Marsupial Genus Chirox," *Am. Naturalist*, XXI, 469, 566–67.
26. COPE, E. D., 1887. "Puerco," *Am. Naturalist*, XXI, 450–51.
27. WHITE, C. A., 1887. "On the Inter-Relations of Contemporaneous Fossil Faunas and Floras," *Am. Jr. Sci.*, 3d series, XXXIII, 364–74.
28. COPE, E. D., 1888. "The Characteristics of the Vertebrate Fauna of the Puerco Epoch of North America," *Proc. Am. Phil. Soc.* (1888), XXV, 113.
29. COPE, E. D., 1888. "Synopsis of the Vertebrate Fauna of the Puerco Series," *Trans. Am. Phil. Soc.*, XVI, 298–361. Read January 20th.
30. SCOTT, W. B., 1888. "On Some New and Little Known Creodonts," *Jr. Acad. Nat. Science*, 2d series, IX, Part II, 155–85.
31. OSBORN, H. F., 1888. "On the Structure and Classification of the Mesozoic Mammalia," *ibid.*, 186–265.
32. OSBORN, H. F., 1890. "A Review of the Cernaysian Mammalia," *Proc. Acad. Nat. Sci. Phila.*, 51–62.
33. SCOTT, W. B., 1892. "A Revision of the North American Creodonta with Notes on Some Genera Which Have Been Referred to That Group," *Proc. Acad. Nat. Sci. Phila.*, 291–323.
34. CROSS, WHITMAN, 1892. "Post-Laramie Deposits of Colorado," *Am. Jr. Sci.*, 3d series, XLIV, 19–42.
35. EARLE, CHAS., 1893. "On the Systematic Position of the Genus Protogonodon," *Am. Naturalist*, XXVII, 377–79.
36. OSBORN, H. F., 1893. "The Rise of the Mammalia in North America," *Am. Jour. Sci.*, 3d series, XLVI (1893), 379, 392, 448–46; *Proc. Am. Assoc. Adv. Science* (1894), 188–277.
37. OSBORN, H. F., AND EARLE, CHAS., 1895. "Fossil Mammals of the Puerco Beds, Collection of 1892," *Bull. Am. Mus. of Nat. Hist.*, VII, 1–70.
38. SCOTT, W. B., 1895. "Tertiary Lacustrine Formations of America," *Sci.*, n.s., II, 499; *Ann. British Assoc. Adv. Science*, 681–82.
39. SCOTT, W. B., 1895. "On the Creodonta," *Ann. British Assoc. Adv. Sci.*, 719–20.

40. WORTMAN, J. L., 1896. "Psittacatherium, a Member of a New and Primitive Sub-Order of the Edentata," *Bull. Am. Mus. of Nat. Hist.*, VIII, 259–62.
41. WORTMAN, J. L., 1896. "The North American Origin of the Edentates," *Science*, n.s., IV, 865–66.
42. WORTMAN, J. L., 1897. Dr. Matthew Reported on Status of the Puerco Fauna. *Science*, n.s., VI, 152, 852.
43. WORTMAN, J. L., 1897. "The Ganodonta and Their Relationship to the Edentata," *Bull. Am. Mus. of Nat. Hist.*, IX, 59–110.
44. MATTHEW, W. D., 1897. "A Revision of the Puerco Fauna," *Am. Mus. of Nat. Hist.*, IX, Art. xxii, 259–323.
45. DALL, W. H., 1898. Quotes Torrejon as part of Puerco of Cope, *U.S. Geol. Surv. 18th Ann. Rept.*, Part II, 347.
46. OSBORN, H. F., 1898. "Evolution of the Amblypoda," *Bull. Am. Mus. of Nat. Hist.*, 169–218.
47. MATTHEW, W. D., 1899. "A Provisional Classification of the Fresh-Water Tertiary of the West," *Bull. Am. Mus. of Nat. Hist.*, XII, 19–77.
48. OSBORN, H. F., 1900. "Correlation between Tertiary Mammal Horizons of Europe and America," *Annals N.Y. Acad. Sci.*, XIII, 1–64; "Corrélations des horizons de mammifères tertiaires en Europe et Amerique," *Compt. rend.*, 8e Cong.
49. SMITH, JAS. H., 1900. "Studies for Students," essay from U. of Chicago; "The Puerco Formation," *Jr. Geol.*, VIII, 444–71, 448–49.
50. MATTHEW, W. D., 1901. "Additional Observations on the Creodonta," *Bull. Am. Mus. of Nat. Hist.* (1901), 1–38.
51. WORTMAN, J. L., 1901. "The Probable Succession of Certain North American Primates," *Sci.*, n.s., XIII (1901), 209–11.
52. DOUGLASS, EARL, 1902. "Discovery of Torrejon Mammals in Montana," *Sci.*, n.s., XV, 272–73.
53. DOUGLASS, EARL, 1902. "A Cretaceous and Lower Tertiary Section in South-Central Montana," *Proc. Am. Phil. Soc.*, XLI (1902), 202–24.
54. GRANT, MADISON, 1902. "The Origin and Relationship of the Large Mammals of North America," *N.Y. Zoöl. Soc., 7th Annual Report* (1902), 182–207.
55. OSBORN, H. F., 1902. "American Eocene Primates and the Supposed Rodent Family Mixodectidae," *Bull. Am. Mus. of Nat. Hist.* (1902), 169–214.
56. DOUGLASS, EARL, 1903. "New Vertebrates from the Montana Tertiary," *Annals of the Carnegie Museum*, II (1903), 145–200.
57. REAGEN, ALBERT B., 1903. (1) "Geology of the Jemez-Albuquerque Region, New Mexico"; (2) "Puerco Marls," *Am. Geol.*, XXXI, 67–111.
58. OSBORN, H. F., 1904. "Ten Years' Progress in Mammalian Paleontology," *Compt. rend. 6e cong. intern. de zoologie* (1904), 86–113.
59. DEPÉRET, CHARLES, 1905. "The Evolution of the Tertiary Mammals and Importance of Their Migrations," *Compt. rend. de l'Académie des Sciences*, CXLI (1905), 702. (Science du 6 novembre 1905); translated extract by

Johanna Kroeber in *Am. Naturalist*, February, 1908, 109–14, and March, 1908, 166–70.

60. VEATCH, A. C., 1907. "Origin and Definition of the Geologic Term 'Laramie,'" *Jour. of Geol.*, XV, No. 6, 526–49.
61. KEYES, C. R., 1907. "Tertiary Terranes of New Mexico," *Proc. Iowa Acad. Science*, XIV, 223–28.
62. SHALER, M. K., 1907. "A Reconnaissance Survey of the Western Part of the Durango-Gallup Coal Field of Colorado and New Mexico," *U.S. Geol. Surv. Bull. No. 315*, 296–302.
63. HAY, OLIVER P., 1907. "Descriptions of Seven New Species of Turtles from the Tertiary of the United States," *Bull. Am. Mus. of Nat. Hist.*, XXIII, 847–63.
64. OSBORN, H. F., 1907. "Tertiary Mammal Horizons of North America," *Bull. Am. Mus. of Nat. Hist.*, XXIII, 237–53.
65. OSBORN, H. F., AND MATTHEW, W. D., 1909. "Cenozoic Mammal Horizons of Western North America" (Osborn) and "Faunal Lists of Tertiary Mammalia of the West" (Matthew), *U.S. Geol. Surv. Bull. No. 341*.
66. GIDLEY, JAMES W., 1909. "Notes on the Fossil Mammalian Genus Ptilodus, with Descriptions of New Species," *Proc. U.S. National Museum*, XXXVI, 611–26.
67. CROSS, WHITMAN, 1909. "The Laramie Formation and the Shoshone Group," *Proc. Wash. Acad. Sci.*, XI, 27–45.
68. KNOWLTON, F. H., 1909. "The Stratigraphic Relations and Paleontology of the 'Hell Creek Beds,' 'Ceratops Beds,' and Equivalents, and Their Reference to the Fort Union Formation," *Proc. Wash. Acad. Sci.*, XI, 179–238.
69. STANTON, T. W., 1909. "The Age and Stratigraphic Relationships of the 'Ceratops Beds' of Wyoming and Montana," *Proc. Wash. Acad. Sci.*, XI, 239–93.
70. GARDNER, JAMES H., 1909. "The Coal Field between Gallina and Raton Spring, New Mexico, in the San Juan Coal Region," *U.S. Geol. Surv. Bull. 341*, 335–51.

The following papers by Dr. Victor Lemoine relate to the Cernaysian Mammalia of France:

71. 1878. "Communication sur les ossements des terrains Tertiaires Inférieurs des environs de Reims," Soc. d'Histoire Naturelle de Reims, May 8.
72. 1878. "Recherches s. l. ossem. foss. d. terr. Infér. d. Reims; 1re partie, Etude du genre Arctocyon," *Ann. des sc. naturelles*, July 8.
73. 1879. "Comm. s. l. ossem. foss. d. terr. Tert. Infér. d. env. d. Reims," Assoc. Franc. p. l'Avancement des Sciences, August. Reprint, Rheims, 1880.
74. 1880. "Terrains Tertiaires des environs de Reims," Assoc. Franc. p. l'Avancement des Sciences.

75. 1882. "Sur l'Encephale de l'Arctocyon Duelli et du Pleurospidotherium Aumonieri," *Bull. de la Soc. Géol. de France*, 3e sér., t. X, April. Also *Comptes rendus*, April, 1882.

76. 1882. "Sur deux Plagiaulax tertiaires, recueills à. env. d. Reims," *Comptes rendus*, November 20.

77. 1883. "Etude s. l. Neoplagiaulax d. l. faune Eocene Infér. d. env. d. Reim," *Bull. de la Soc. Géol. de France*, 3e sér., t. XI.

78. 1884. "Caractères gén. d. Pleuraspidotherium, etc.," *Comptes rendus*, December.

79. 1885. "Etude s. quel. mamm. de petite taille de la faun. Cern. d. env. d. Reims," *Bull. de la Soc. Géol. de France*, 3e sér., t. XIII.

80. 1887. "Sur le genre Plesiadipis, etc.," *Comptes rendus*, January.

81. 1888. "Sur. quel. mamm. carnaissers recueil. dans l'Eoc. Inf. des env. Reims," *Comptes rendus*, February.

The following volume on the Cretaceous and Tertiary formations of Patagonia is descriptive of the fauna of the "Notostylops" beds and contains an exhaustive bibliography relating to the subject:

82. AMEGHINO, FLORENTINO, 1906. "Les formations sédimentaires du Crétacé Supérieur de Tertiaire de Patagonia," *Annales Museo Nacional de Buenos Ayres*, ser. 3, Vol. VIII.

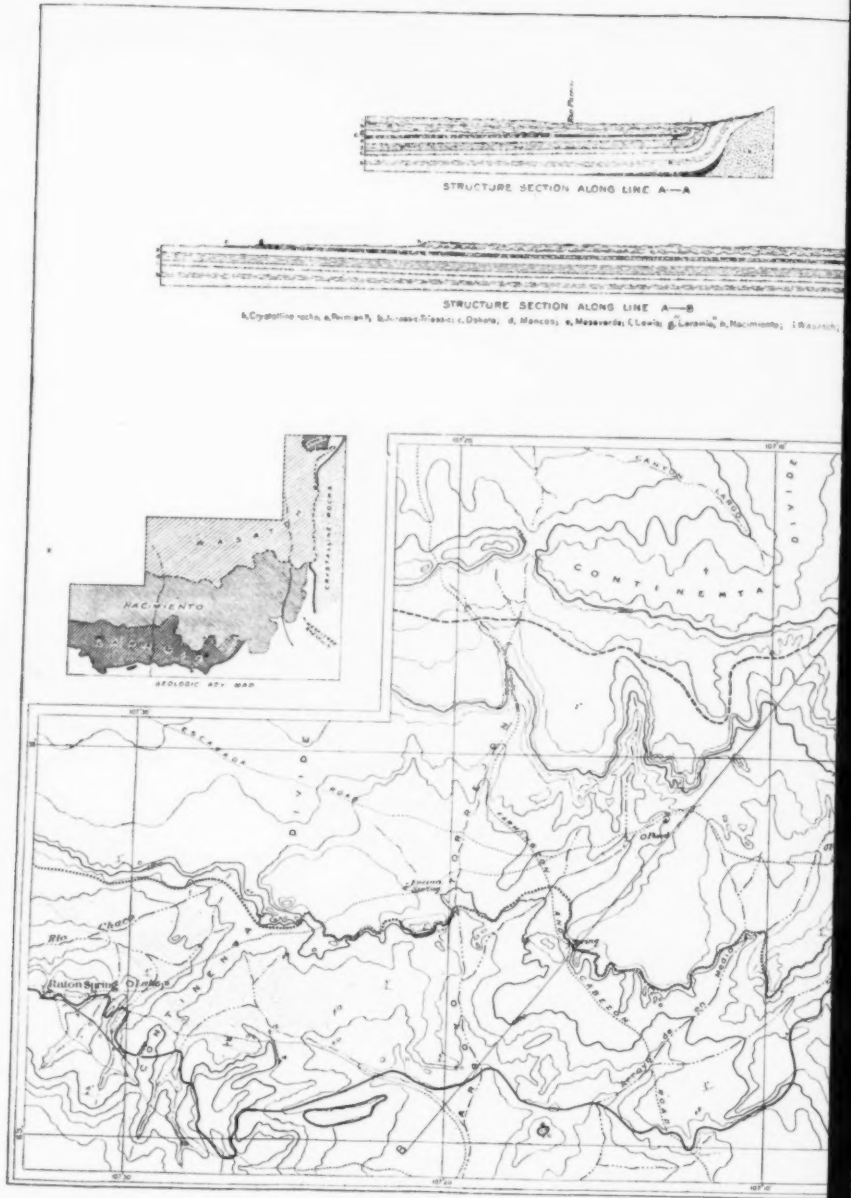
A NEW EROSION CYCLE IN THE GRAND CANYON DISTRICT, ARIZONA

H. H. ROBINSON

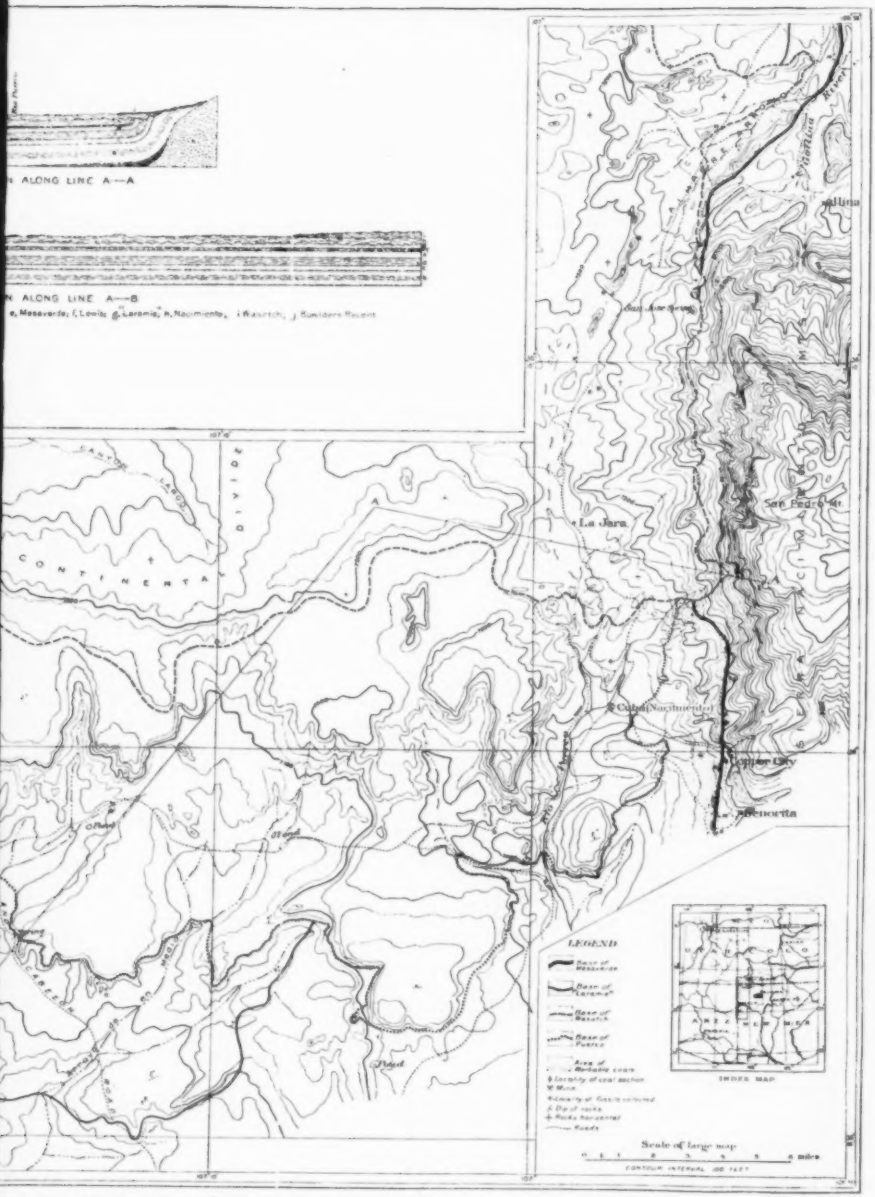
INTRODUCTION

The Grand Canyon District of Arizona possesses a particular interest for the geologist in that its history, at least from the beginning of the Tertiary, must be interpreted almost entirely from physiographic data; that is to say, the region has been subject to erosion for so long a period that stratigraphic evidence is lacking. The absence of such evidence, which long usage has fixed as the conventional means of interpreting geologic history, may have caused, perhaps, some doubt to be felt as to the reality of the conclusions originally reached by Dutton in 1882 in regard to the history of the region, for at that time the data of physiography were in a more or less embryonic state and their interpretative value was hardly recognized. Indeed, Dutton's report on the Tertiary history of the Grand Canyon District[1] was a pioneer work in this branch of geology and its significance becomes increasingly apparent with the passage of time. Today conditions are changed, physiography has taken its place as a systematic science, and the relation between topographic forms and the conditions under which they may originate may be considered as resting on a reasonably broad and well-established foundation. Thus conclusions based upon physiographic evidence are now accepted as of equivalent value to those based on older and more conventional lines of evidence, where twenty-five years ago they were looked upon with skepticism by the majority of geologists who had not had a physiographic training. That there was good reason for this attitude is well illustrated by the new erosion cycle described in this article, for the facts upon which it is based have been known for twenty-five years without their significance being fully

[1] *Tertiary History of the Grand Canyon District, Arizona, with Atlas* (Monogr. II, U.S.G.S., 1882).



MAP OF THE PUERCO AND TORREJON T
NEW MEXICO.



ERCO AND TORREJON TYPE LOCALITY
NEW MEXICO.

appreciated, thus indicating the recent nature of the growth of physiography from the descriptive to the broader interpretative stage.

REVIEW OF FORMER WORK

It will assist in understanding the bearing of this new cycle of erosion on the Tertiary history of the region if a partial summary of some of the former work is first presented. The actual amount is, indeed, not great, considering the length of time the region has been known and its interest recognized; possibly the extent of the field and the evident inaccessibility of much of it have exercised a deterrent influence.

The nature of the plateau problem was clearly appreciated by Newberry who in 1858 was the second geologist to traverse the region. His route lead him along the southern side of the Grand Canyon, and the conclusion he reached from the character of that and other parts of the plateau was that erosion had been the predominant factor in producing the relief. The following quotation will give his point of view:

> . . . . Before returning to the details of the local geology of our route, I ought perhaps to refer briefly to two questions of general importance, which would naturally suggest themselves to any geologist who should traverse the table-lands west of the Rocky Mountains, or should receive an accurate description of them from others.
>
> The first of these questions is: To what cause is due the peculiar topographic features of the surface of the table-lands—where different formations succeed each other in a series of steps, which generally present abrupt and wall-like edges—the more recent strata occupying the highest portion of the plateau?
>
> The first question belongs appropriately to the subject of surface geology, and will be referred to again. I may say here, however, that, like the great canyons of the Colorado, the broad valleys bounded by high and perpendicular walls *belong to a vast system of erosion, and are wholly due to the action of water*. Probably nowhere in the world has the action of this agent produced results so surprising, both as regards their magnitude and their peculiar character.[1]

The first extended account of the region, however, did not appear until 1882 when Dutton's *Tertiary History of the Grand Canyon District* was published. The history of the region as

[1] *Report on the Colorado River of the West. Explored in 1857–1858, by Lieut. J. C. Ives.* Washington, 1861. Part III, Geological Report by J. S. Newberry, p. 45.

deciphered by Dutton, and omitting many details of an admittedly speculative character, comprised the following events:

1. A period of great denudation during which a thickness of strata averaging 10,000 feet was removed from over an area of 13,000 to 15,000 square miles. This period ended somewhere about the close of the Miocene.

> The Grand Canyon platform then may have lain near sea-level, and the remnants of Mesozoic beds . . . . were gradually obliterated, and the entire region was planed down to a comparatively smooth surface [p. 119] . . . . and was at a base-level of erosion [p. 120].

2. A canyon-cutting cycle. This was initiated by an epoch of faulting at the beginning of the Pliocene which elevated the region from 2,000 to 3,000 feet above the level it occupied at the close of the period of the great denudation.

> At the epoch when the cutting of the present Grand Canyon began, no doubt the region at large presented a very different aspect from the modern one. While the greater part of the denudation of the Mesozoic had been accomplished, there were some important remnants left which have been nearly or quite demolished in still more recent times [p. 223]. . . . . The uplifting forces suspended operations for a time, and the drainage system sought a new base-level. During this paroxysm of upheaval the outer gorge of the Grand Canyon was cut, the river corrading down to the level of the esplanade in the Kanab and Uinkaret divisions, but below that horizon in the Kaibab [p. 226]. . . . . The process of erosion during this second period of base-level was occupied in the only possible work under the circumstances, viz., sapping the newly formed cliffs of the canyon. The cliffs, thus attacked, receded away from the river, gradually developing the broad avenue of the outer chasm [p. 121]. . . . . We now come to the final upheaval which brought the region to its present condition. . . . . A new paroxysm of upheaval set in . . . . amounting probably from 3,000 to 4,000 feet. The narrow, inner gorge of the Toroweap was swiftly cut and it is in this respect a type of the lower depths of the entire canyon. . . . . The epoch at which this latest upheaval took place is no doubt a very recent one in the geologic calendar. It began most probably near the close of the Pliocene [p. 228].

The history of the region, as worked out by Dutton, may be tabulated as follows:

I. The period of great denudation lasting until the close of the Miocene.
II. Uplift by folding (?) and faulting at close of Miocene.
III. The canyon cycle of erosion.
  a) Cutting of outer gorge of Grand Canyon during the Pliocene.
  b) Uplift by faulting at close of Pliocene.
  c) Cutting of inner gorge of the canyon during the Quaternary.

Davis,[1] as the result of two trips through the region, advanced several pertinent arguments supporting the broad conclusion of Dutton that the Grand Canyon District had experienced two cycles of erosion separated by a period of pronounced uplift. In the absence of local fossiliferous evidence he designated the earlier period of the great denudation as the plateau cycle and the later one, in which the canyon cutting occurred, as the canyon cycle. Especially suggestive was his argument in favor of two cycles based on the relatively great retreat of the cliffs from the canyon on its north side as compared with the slight retreat of the upper walls of the canyon from the river, the correctness of which was later confirmed by independent evidence (*a*, p. 118). He pointed out that the esplanade of the Kanab and Uinkaret sections of the canyon was best explained as a structural feature and from a variety of considerations concluded "that while many partial cycles of erosion may have preceded the long pause during which the broad denudation of the plateaus was completed, only a single uplift and a single downcutting are recorded in the canyon" (*a*, p. 185). This conclusion has since been confirmed by Dr. L. F. Noble as the result of detailed field work in the canyon in the vicinity of Bass's camp.[2]

Of critical significance was the recognition by Davis of an important period of faulting during the plateau cycle of erosion distinctly separated from the later faulting at the beginning of the canyon cycle. Definite evidence was obtained that relief of at least 1,000 feet, due to this faulting, was obliterated during the plateau cycle and that by the end of that cycle the region in general had been reduced to a peneplain.

In speaking of the reduction of the region to a peneplain at the close of the period of great denudation, Davis says:

> It therefore seems legitimate to say that the peneplain, so far as one was developed at the close of the first cycle, lay in the Permian formation at some unknown height above the present plateau surface in the Kanab district; and that the Carboniferous platform as now exposed in the Kanab Plateau is a

[1] *a*) "An Excursion to the Grand Canyon of the Colorado," *Bull. Mus. Comp. Zoology, Harvard College*, XXXVIII, May, 1901; *b*) "An Excursion to the Plateau Province of Utah and Arizona," *ibid.*, XLII, June, 1903.

[2] Unpublished manuscript.

stripped and somewhat dissected plain [*a*, p. 139]. . . . . Since the uplift by which the canyon cycle was introduced, sufficient time has elapsed for an extensive removal of the weaker Permian strata from the plateau surface. . . . . Even the resistant upper Aubrey strata, revealed by the stripping of their Permian cover, early in the canyon cycle, have suffered a significant amount of dissection, as seems to be the case over much of the Kanab Plateau; but the dissection here is not so mature as that by which the higher Kaibab is characterized [*a*, p. 137].

The general conclusions reached by Huntington and Goldthwait, as the result of a study of the Toquerville District, Utah,[1] coincided with those of Davis outlined above, but as the work was of considerable detail they were able to present the problem with somewhat greater fulness than had previously been done. In particular they were able to show "that at the end of the interfault cycle of erosion (the period of great denudation) the whole country was physiographically mature or even old. Certain regions of soft strata, chiefly near the Colorado River, had been reduced very nearly to base-level forming the Mohave peneplain."

Evidence has been presented by the writer[2] showing that the region about the San Francisco Mountains,[3] south of the Grand Canyon, was also reduced to a peneplain which involved not only soft Permian and Triassic strata but also the highly resistant upper Aubrey cherty limestone. It was concluded from a study of the literature that the peneplain most probably covered the entire southern portion of the present Colorado Plateaus and extended, in the Bradshaw Mountains, into the Basin Range country of Arizona. The remnants of the peneplain are sufficiently numerous to make it certain that practically the entire Grand Canyon District was reduced to base-level at the close of the period

[1] "The Hurricane Fault in the Toquerville District, Utah," *Bull. Mus. Comp. Zoology, Harvard College*, XLII, February, 1904.

[2] "The Tertiary Peneplain of the Plateau District, and Adjacent Country, in Arizona and New Mexico," *Am. Jour. Sci.*, XXIV (August, 1907), 109–29.

[3] The term "San Francisco Mountains" is here used to designate a group of six large and several hundred small volcanoes and their associated lavas, which covers an area of some 2,000 square miles on the plateau south of the Grand Canyon. The group takes its name from San Francisco Mountain, the largest mountain volcano of the region.

of great denudation. The peneplain was developed over much of the region on the soft Permian and Triassic strata and owes its preservation to a capping of basalt. The extent of the peneplain and the fact that it is developed across the basset edges of strata varying in hardness from a compact sandstone to a barely consolidated marl, as at Black Point in the Little Colorado Valley and elsewhere, force the conclusion that a long period of time is represented, that the base of control was an oceanic body of water, and that consequently the region stood approximately at sea-level.

The history of the region, following Huntington and Goldthwait, may now be tabulated as follows:

I. Period of folding and flexing.
II. Erosion period.
III. The first faulting.
IV. Inter-fault cycle of erosion. Region reduced to a peneplain at close.
V. The later faulting.
VI. The post-fault canyon cycle of erosion.
Stripping of weak strata down to the upper Aubrey cherty limestone. Cutting of deep canyons. Refreshing of cliff profiles.

As bearing on what is to follow it may be noted that Davis, and also Huntington and Goldthwait, considered that the peneplain developed on the Permian and Triassic formations marked the close of the period of great denudation and that the stripping of these strata and the consequent exposure of the upper Aubrey limestone—the present surface rock of the region—occurred after the uplift which introduced the canyon cycle. Dutton also recognized the existence of a peneplain on Permian strata beneath the basalt cap of Mount Trumbull and at other localities (p. 224), and he also considered that the present surface of the plateau was likewise developed at a base-level of erosion (p. 118). He did not give these two planes of erosion distinct interpretative values, but used them as common evidence that the region stood at a low elevation at the close of the period of the great denudation. The proper discrimination between these two planes of erosion, as will appear in the sequel, gives the clue to an essential feature in the history of the Grand Canyon District which has not thus far been fully recognized.

THE ADDITIONAL EROSION CYCLE

The erosion cycle to which the remainder of this article will be largely devoted followed after the development of the extensive peneplain at the close of the period of great denudation but before the uplift which introduced the canyon cycle of erosion, and is to be associated with the former cycle rather than the latter. It was characterized by the widespread removal of a notable thickness of Permian and Triassic strata and the development of a thoroughly mature topography on the underlying resistant upper Aubrey cherty limestone—the present surface rock of the region. It will be called the post-peneplain cycle of erosion. The preceding cycle, which closed with the reduction of the region to a peneplain, will be designated as the peneplain cycle, while the latest cycle, as formerly, will be called the canyon cycle of erosion.

A striking feature of the Grand Canyon District, which impresses even the casual observer, is the pronounced contrast between the broad expanse of the smooth or but gently undulating surface of the plateau and the deep and precipitous walled canyons carrying the present drainage, a contrast that is highly suggestive of different conditions of origin.

In the region south of the canyon, with which the writer is particularly acquainted, the surface of the plateau is etched by an extensive system of shallow valleys of thoroughly mature form. They were first described by Newberry, in 1858, in the following terms:

> Where we crossed this divide it had the character of an elevated plateau, of which the surface has been considerably modified by erosion, and now presents many broad and shallow excavated valleys [p. 58].

Davis, in speaking of these valleys on the Coconino Plateau, says:

> . . . . We were much impressed with the maturity of their graded sides and floors, in contrast to the youthful expression of the precocious canyon. . . . . Furthermore, the contrast between the rapid wasting of the cliff in the canyon walls and the slow change of the mature valleys on the plateau strongly suggests that the processes represent different cycles of erosion [*a*, p. 120, and Fig. 2].

These old valleys are also well developed farther south in the vicinity of the San Francisco Mountains. Figs. 1 and 2 illustrate

the one which is located just southeast of Flagstaff. The perfect maturity of form which characterizes the small branches even to their very heads is well shown in Fig. 1. The slightly meandering course and mature side slopes of the main valley are seen in Fig. 2. The alluvial filling is suggestive of a well-graded condition of the stream, especially when taken in connection with the gently sloping sides. It is, however, a significant fact that the alluvium, which was deposited after the valley had acquired its

FIG. 1

mature form, extends to the head of the valley so that its deposition was independent of the grade.[1]

The region south of the canyon is, indeed, a network of these mature valleys, and it is to be presumed that the corresponding districts elsewhere are also covered with them. They occur on the Marble Platform, but have not been specifically described

[1] The same phenomenon is strikingly illustrated by the heavy alluvial mantles of the large volcanoes of the region which, on San Francisco Mountain, appear to be associated with glacial deposits. These alluvial deposits are now undergoing dissection, thus indicating a reversal of the conditions under which they were laid down.

as present on the Kanab Plateau. Apparently they are best preserved in those localities where they were developed on the upper Aubrey cherty limestone.

The valleys of the Kaibab (and also the Coconino) Plateau have been described by Davis as follows:

> The limestone [upper Aubrey] capping these plateaus is maturely dissected. Broad-floored, well-graded valleys with gently sloping sides ramify through the uplands in a most perfect manner, presenting a maturely developed form even to their heads; and this in spite of the fact that they are nearly always dry, for the wash of waste down their sides and along their floors is accomplished only during the rains and thaws of winter and occasional showers of summer [*a*, p. 120].

The above description embraces the valleys of the Coconino Plateau and also applies without alteration to the similar valleys farther south in the vicinity of the San Francisco Mountains. There is, therefore, little doubt, as will appear from later considerations, that all these valleys were developed in the same cycle of erosion. It may be noted, moreover, that, as these valleys had maturely developed form even to their heads, their lower courses must have originally possessed at least equal maturity of form, so that there is no doubt as to the thoroughly mature development of the topography throughout the Grand Canyon District during this cycle.

The post-peneplain cycle of erosion is separated from the preceding cycle of the great denudation, which closed with the widespread development of a peneplain, not only because of differences in topographic expression, but primarily because the mature topography occurs at a level distinctly below that at which the peneplain is found. This is a fact that is perfectly evident at many localities where structural complexities are absent. As, however, the peneplain involves a considerable thickness of strata ranging from the upper Aubrey (upper Carboniferous) limestone through Triassic formations, while the mature topography, so far as known, is developed, or at least preserved, only on the upper Aubrey limestone, the actual difference between the two planes of erosion is a variable one depending upon the thickness of Permian and Triassic strata that may be present at any locality.

In the vicinity of Flagstaff, close to the boundary between the upper Aubrey limestone and Moencopie (Permian) formation, the difference between the two planes of erosion is not over 200 feet. Along the eastern side of the Black Mesa, farther south, it ranges from 400 to 600 feet. At Cedar Ranch, 15 miles northerly from San Francisco Mountain, it has increased to 700 feet, while at Red Butte, nearer the canyon, it reaches a maximum of about 1,000 feet. Corresponding differences between the two planes of erosion

FIG. 2

occur on the north side of the canyon. In the southwest section of the plateau the difference is practically nothing, since the peneplain was developed on the upper Aubrey limestone and the forces of erosion, which were powerful enough to remove the in general weak Permian and Triassic strata elsewhere, had little effect on the resistant basalt capping the peneplain and on the underlying limestone. The only locality in the district which appears to have surely risen above the peneplain at the close of the period of the great denudation is the Kaibab Plateau. The surface

of this plateau is a stripped structural one formed by the upper Aubrey cherty limestone, and its elevation above the surrounding plateau country is due principally to monoclinal folding which occurred not later than the very beginning of the erosional history of the region in the Eocene. It must be supposed, then, that the surface of the Kaibab Plateau was reduced to maturity or old age, coincident with the development of the peneplain, and that its present mature topography represents a continuation of the process in the post-peneplain cycle of erosion.

The separation of the post-peneplain cycle from the canyon cycle which followed is based in part on the wide difference in the character of their drainage systems, the one perfect in its maturity, the other equally perfect in its youthfulness, and the fact that the canyon cutting has to some extent destroyed the mature valleys. There is abundant evidence that this latter process is still in progress; it is very plainly seen on both the north and south sides of the Kaibab section of the Grand Canyon where the older mature valleys are being consumed by the widening of the youthful canyon. Further, the courses of many of the partly consumed valleys lead away from the canyon, thus indicating that there has been such a radical readjustment of drainage lines in the canyon cycle as to bring about definite changes in their direction, and this is especially noticeable in the case of the trunk stream of the region—the Colorado River.

The tracing out of the mature valleys and reconstruction of the drainage system of the post-peneplain cycle of erosion is evidently an important problem which must be worked out before a satisfactory explanation for the location of the present canyon system of drainage can be offered. For the reconstruction of this mature drainage system should permit a definite idea of the attitude of the land during the post-peneplain cycle to be formed and consequently indicate the extent and magnitude of the regional warping which followed. Of equal importance, also, would be a study which would permit the reconstruction over an extensive area of the peneplain of the preceding cycle of erosion; this would assist in determining not only the extent of the warping but also the magnitude of the faulting which has occurred at various times in

the history of the region. Indeed, if the supposition is as correct as it appears to be that the ancestors of the Colorado River, several generations removed, had their courses originally determined by the configuration of the peneplain, it is evident that the peneplain must have embraced practically the entire area of the Colorado plateaus, and consequently this problem presents a very wide interest.

A comparison of the extent of erosion, taken in connection with the conditions under which it was accomplished, during the post-peneplain and canyon cycles furnishes added reason for separating them. The figures which follow are, of course, the roughest approximations, but they may serve to give some idea of the amount of material eroded. And first it may be noted that the period of the great denudation is distinctly in a class by itself. Taking Dutton's estimate of an average thickness of 10,000 feet of strata removed over an area of 13,000 square miles, the volume eroded is equal to 25,000 cubic miles; or a more conservative estimate, with the thickness of strata placed at 6,000 feet, is 16,000 cubic miles. The amounts of material eroded during the post-peneplain and canyon cycles were very much smaller; it is estimated that their combined volume is only about 5 to 10 per cent of that removed in the period of the great denudation.

The amount of material eroded during the post-peneplain cycle is placed at 800 cubic miles. This is based on the removal of an average thickness of 500 feet of Permian and Triassic strata from an area of some 8,000 square miles. The latter figure shows how widespread was the stripping of the soft strata overlying the resistant upper Aubrey limestone during this cycle. In view of so extensive a denudation ending, as it did, with the development of a mature topography of only slight relief, the conclusion seems justified that the region during this time must have stood at no great elevation above the sea.

The amount of material eroded during the canyon cycle is considered as equal to the volume of the various canyons of the region, which practically means the Grand Canyon and its tributaries, and in addition some volume of soft strata removed by stripping. This latter process has been confined to limited areas and the volume of material thus removed cannot well be calculated;

it is, therefore, arbitrarily placed at 50 cubic miles, which allows for the removal of over 100 feet of strata from an area of more than 2,000 square miles. Including this, the total volume of material eroded during the canyon cycle is placed at 600 cubic miles.

A contrast may thus be drawn between the removal of 800 cubic miles of Permian and Triassic strata over an area of some 8,000 square miles with the development of a mature topography on the stripped resistant limestone—the post-peneplain erosion—while the land stood at a fairly low elevation, and the erosion of 600 cubic miles of material as the result of canyon cutting—the canyon erosion—with the land at, or rising to, a high elevation. If it is asked whether the erosion above described occurred in a single cycle, the answer must be in the negative. For erosion in the canyon cycle has been proceeding at an extremely rapid rate and consequently the 600 cubic miles of material removed in the cutting of the youthful canyons indicates much too short a time to permit the stripping of the 800 cubic miles of Permian and Triassic strata from the surface of the plateau and the development of the mature topography on the underlying limestone. To consider the post-peneplain erosion as occurring in the same cycle as the canyon erosion is to include the greater within the lesser, thus producing an anomalous result. If, on the contrary, a thousand cubic miles of material had been eroded in the canyon cutting and but a few hundred stripped from the surface of the plateau, and especially if the mature topography had been developed on weak instead of resistant strata, it might be supposed to have entirely occurred in a single cycle. But in view of the evidence furnished by the mature valleys, the differences in direction between the mature and canyon systems of drainage, the relative amounts of erosion in the post-peneplain and canyon cycles, and the differences in the resistance of the strata eroded in the two periods, the conclusion is fully justified that the erosion of the post-peneplain and canyon cycles could not well have taken place in a single cycle and consequently the post-peneplain cycle must be given an independent rank.

An important consideration in separating the post-peneplain cycle of erosion from the preceding peneplain cycle and especially from the succeeding canyon cycle lies in the fact that the mature

topography of the intermediate cycle was developed on what was evidently, under the circumstances, a highly resistant formation, namely, the upper Aubrey cherty limestone. This formation is as resistant, for instance, as the basalt which was erupted after the development of the peneplain at the close of the period of the great denudation and is very much more resistant than the overlying Permian and Triassic strata remaining after the development of the peneplain. A comparison of the amount of erosion during the post-peneplain cycle in the extreme southwestern part of the plateau, where the limestone and basalt were present, and the remainder of the district which was covered, for the most part, with Permian and Triassic strata, is very instructive upon this point. The basalt in the former locality was only moderately dissected, and the limestone only slightly, as the result of erosion during the whole of the post-peneplain cycle, while elsewhere Permian and Triassic strata up to a maximum thickness of over 1,000 feet were removed. The difference suggests how erroneous might be an idea of the erosion based on incomplete observations. The point to be noted is that the development of a thoroughly mature topography, even of a low degree of relief and representing no great removal of material, on so resistant a formation as this limestone is indicative of an erosion interval as long in itself, perhaps, as that marked by the canyon cutting. And when to the time required for the development of the mature topography on the resistant limestone is added that necessary for the previous extensive and widespread removal of the overlying Permian and Triassic strata an interval is indicated which was probably much longer than that covered by the cutting of the youthful canyons. Moreover the strata involved in the latter process are not all so resistant as the upper Aubrey limestone on which the mature topography was developed. Several important formations are distinctly weaker, as, for example, much of the lower Aubrey red sandstone, and the presence of these weaker beds tends to increase the difference between the lengths of time required for the canyon cutting and post-peneplain erosion in favor of the latter. The interval covered by the post-peneplain cycle of erosion was very much shorter, of course, than that of the preceding period of the great denudation,

but, on the other hand, it certainly appears to have been much longer, taking the various factors into account, than the time required for the canyon cutting.

The evidence, therefore, indicates that the post-peneplain cycle of erosion should be clearly marked off from the preceding peneplain cycle and from the succeeding canyon cycle. The history of the region, as previously given, must be amended, consequently, by saying that after the close of the peneplain cycle of erosion, and the widespread eruption of basalt, another period of erosion began during which unprotected Permian and Triassic strata up to a thickness of 1,000 feet were removed from an area embracing the greater part of the Grand Canyon District. Where these strata were protected by the basalt their removal was incomplete and remnants now form the mesas and buttes, such as Mount Trumbull and Red Butte, which are found at various localities. It is also to be inferred from the widespread removal of these strata that the high cliffs bounding the region on the north and east experienced a further retreat. Davis says: ". . . . in the case of the Vermillion cliffs at Pipe Spring the retreat is likely, it seems to me, to have been several miles at least" (*b*, p. 37). After the removal of the Permian and Triassic strata erosion proceeded still farther and developed a mature topography of low relief in the underlying and resistant upper Aubrey cherty limestone and to a less extent in other formations. The revival of the forces of erosion is supposed to have been brought about by a slight elevation of the region above its stand at the close of the peneplain cycle. It is considered that the uplift was associated with a period of faulting, which has thus far not been specifically recognized. The movements of different periods have so often taken place along the same line of displacement in this region that detailed study is necessary in order to discriminate between them.[1]

[1] In a paper entitled "A Geological Excursion in the Grand Canyon District" (*Proc. Boston Soc. Nat. Hist.*, May, 1909) and published since the above was written, Dr. D. W. Johnson describes a third period of faulting on the Hurricane displacement in the vicinity of Toquerville, Utah. It occurred between the faulting of the plateau cycle—the first faulting of Huntington and Goldthwait—and that which introduced the canyon cycle of erosion, and amounted to about 1,000 feet. This appears to be the faulting which is here supposed to have immediately preceded the post-peneplain cycle of erosion.

The history of the Grand Canyon District, with the post-peneplain cycle of erosion introduced, may now be summarized as follows:

I. Period of folding and flexing.

II. Erosion cycle.

III. The first period of faulting. A period of extensive faulting.

IV. The peneplain cycle of erosion. This cycle closed with the widespread development of a peneplain. Relief produced by faulting (III) entirely obliterated. Widespread volcanic activity, marked by the eruption basalt, occurred shortly after the development of the peneplain and while the region still stood close to sea-level.

V. The second period of faulting. Faulting probably of less magnitude than that of the first and third periods.

VI. The post-peneplain cycle of erosion. Widespread stripping of Permian and Triassic strata and development of a mature topography on the underlying beds, principally the upper Aubrey limestone, at a horizon ranging from zero to 1,000 feet below the level of the peneplain. Further retreat of the high cliffs on the north and east sides of the district. Land stood at no great height above the sea.

VII. The third period of faulting, with broad regional uplift. Region raised from 4,000 to 6,000 feet above the position it occupied at the close of the post-peneplain cycle.

VIII. The canyon (present) cycle of erosion. Marked by the development of a canyon system of drainage of extreme youthfulness. Refreshing of cliff profiles. Erosion otherwise very slight.

The history above outlined is considerably more complex than that presented by Dutton and is believed to be complete so far as the principal events are concerned. It differs from previous interpretations in introducing the post-peneplain cycle of erosion, and it is felt that this cycle rests on evidence fully as conclusive as that which establishes the separate existence of the peneplain and canyon cycles of erosion. It removes the anomaly in the previous explanations of the widespread stripping of a very considerable thickness of Permian and Triassic strata and development of a mature topography on the resistant upper Aubrey limestone in the same cycle that has witnessed the cutting of the youthful canyons.

POSITION OF EVENTS IN GEOLOGIC TIME

While the history of the Grand Canyon region, on the whole, possesses a very reasonable definiteness, the problem of placing the several events which comprise it in geologic time is quite unsatis-

factory, as there is no direct evidence to be derived from the district itself. The only method of attack is by correlation with the neighboring Basin Range country of Nevada, which in itself has not been studied in any great detail. Yet, notwithstanding the tentative nature of any conclusions that may be reached, it is desired to present the results of such a correlation, not only because they differ from those previously reached, but also because it is believed, in the light of known geologic events of recent date—especially in California—that they possess a very considerable suggestive value and may be useful to those who may later have occasion to study this general region.

The folding and flexing (I), as represented by the Kaibab and Echo Cliff monoclines, does not antedate the middle part of the Eocene, since the disturbance involves strata of Lower Eocene age in the high plateaus of Utah.[1] It seems probable, also, from other considerations, that it did not occur later than the end of the Eocene. The folding in the Grand Canyon District, to all appearances, is of the same age; it must be carefully distinguished, however, from certain broad warpings of much later date. Up to the present the folding and flexing movements have received much less study than the later faulting, although they are fully equal to the latter in importance, when their magnitude and extent, and the geographic changes involved are considered.

The correlation of greatest probability is that between the peneplain developed at the close of the peneplain cycle of erosion (IV), and the mature topography and local peneplains of the Basin Range country of southern Nevada and of Arizona. The point has not been so thoroughly studied as is desirable, but it seems clear to the writer, as the result of reconnaissance work, that there was originally a direct continuity between the maturely dissected Basin Ranges with local peneplains extending from their footslopes and the more distant highly developed peneplain of the present plateau region; they were the related parts of a single physiographic province. There is little doubt that this transition may be actually traced in Arizona, with only minor breaks, from the Bradshaw Mountains through the Black Hills on the west side of the

[1] Dutton, *op. cit.*, 74.

Verde Valley into the Black Mesa on its east side. At many points in the Black Hills and the mountains the remnants of the plain are capped by a basalt identical in character with that which covers the peneplain on the Black Mesa. Also the amount of erosion that has occurred since the basalt was erupted on the plain east of the Bradshaw Mountains compares very favorably with that of the post-peneplain cycle in the near-by present plateau region.[1] As both areas were situated in local drainage basins under similar climatic control and as the strata involved, judging from more recent results in the Grand Canyon of the Colorado, possessed approximately equal erodability, it may be concluded that the topography of the two areas was of contemporaneous origin.

The date at which the Basin Ranges originated as tilted block mountains possesses, therefore, a critical value, since it marks the time between which and the present the most clearly known events in the history of the Grand Canyon District occurred. This date is fixed by the age of certain formations—Pah-Ute of King and Siebert of Spurr—which were involved in the range-making movement. A Miocene age was originally assigned to these beds by King[2] and this has since been concurred in by Spurr,[3] Ball,[4] and Ransome.[5] The determination is not so positive as might be desired, nor is it certain that the entire Miocene is represented. In the absence of evidence to the contrary, however, it will be assumed that the sedimentary beds involved in the range-making do represent the whole of the Miocene. The probable correctness of this assumption is indicated by following consideration. If the strata involved in the mountain-making represented only the earlier part of the Miocene and the faulting which gave rise to the ranges as tilted block mountains occurred, for instance, in the middle of the Miocene, then the succeeding formation should be of late Miocene age, since the region during this time was a land area and the deposits were of a local nature. On the contrary, however, the next youngest formation is of Pliocene age; it rests unconformably on the older tilted strata of the ranges generally in a horizontal or

[1] H. H. Robinson, *op. cit.*, 120.

[2] *Explor. 40th Parallel*, I, 412–24.

[3] *U.S.G.S.*, XLII (1905), 66.

[4] *U.S.G.S.*, Bull. 308 (1907), 32.

[5] *U.S.G.S.*, LXVI (1909), 66.

but slightly disturbed position. On this basis, then, the Basin Ranges originated as tilted block mountains at the close of the Miocene.

It is to be noted that the relief produced by the extensive faulting, which followed in the present plateau region next after the Eocene folding, was entirely reduced in the development of the peneplain. A very considerable interval, therefore, must have intervened between the time of the faulting and the final degradation of the region to a peneplain. In view of the magnitude of the faulting and its time relation to the peneplain, it seems permissible to correlate it with that which gave rise to the Basin Ranges as tilted block mountains, and which likewise followed a period of folding.

After the faulting at the close of the Miocene the newly formed block mountains of the Basin Range region were attacked by erosive forces and reduced to mature forms. Contemporaneously local peneplains were developed, under favorable conditions, about the footslopes of the ranges,[1] while at greater distances—in the present plateau region—a highly developed peneplain covered thousands of square miles. There is at present no direct evidence to tell when this erosion cycle came to an end, so that it is necessary to make an assumption as to this date. It is the writer's opinion, based on the character and extent of the erosion in the several cycles through which the Grand Canyon region has passed, that the close of the peneplain cycle should be placed at the end of the Pliocene. This appears to be the most probable date when the volume of the erosion during the peneplain cycle and the widespread base-leveling are compared with the extent and nature of the erosion during the post-peneplain and canyon cycles. The point is one that is difficult to settle and may always remain, perhaps, a matter of individual judgment.

As the result of the foregoing assignment of dates, the post-peneplain and canyon cycles of erosion, with the pronounced faulting that came between them, are placed in the Quaternary. This is at variance with previous ideas. Dutton, for instance, spread the canyon cutting alone over both the Pliocene and Quaternary;[2] a previous correlation by the writer confined it to the

[1] Ball, *op. cit.*, 41. [2] *Ibid.*, chap. xii.

Quaternary,[1] while the present one throws it still farther forward into the latter part of that period. Granting the correctness of the assumptions previously made, the reasonableness of this conclusion seems evident when the relative amounts of erosion during the post-peneplain and canyon cycles, and the wide difference in the conditions under which it was accomplished are considered, although the correctness of the results in general remains for future demonstration. It is suggestive of the truth of the conclusion here reached, however, that Lee in his bulletin entitled "A Geological Reconnaissance of Western Arizona"[2] describes, at a number of localities, a thick unconsolidated gravelly formation that has experienced marked faulting. In speaking of this formation as it occurs in the Chemehuevis Valley, he says:

> The older gravels are horizontally bedded in some places but in others are faulted and highly inclined. . . . . In general appearance they resemble the Temple Bar Conglomerate and are provisionally correlated with it.[3]

The suggestive point is that the Temple Bar Conglomerate is considered as being of Quaternary age and deposited after a last period of pronounced faulting at the opening of the Quaternary, so that it should be comparatively undisturbed. If one may judge, however, from Lee's descriptions and cross-sections, the formation which he provisionally correlates with the Temple Bar Conglomerate has been very strongly faulted and tilted at a number of localities. This is easily explained, and Lee's correlation strengthened, if the major faulting which introduced the canyon cycle of erosion occurred during instead of at the beginning of the Quaternary. For with the faulting occurring during the middle or latter part of the Quaternary there would still have been ample time in the earlier part of that period for the deposition of heavy alluvial deposits upon the lowlands bordering the plateau country.

There are three other points which may receive further mention. One is that on the basis of the erosion cycles in the Grand Canyon district the mature topography of the Basin Ranges of southern Nevada and of Arizona should be considered as the result not only of the peneplain but also of the post-peneplain cycle of erosion. The former was much the more important, but the latter may have introduced significant modifications. Whether they would be

[1] *Ibid.*, 111. [2] *U.S.G.S.*, Bull. 352 (1908). [3] *Ibid.*, 43–44.

recognizable in the ranges themselves is questionable. Judging from the changes produced by erosion during the post-peneplain cycle in the plateau region, they should be most easily recognized about the footslopes of the ranges and in the peneplained areas.

A second point is that while the Basin Range country and plateau region, as they are known today, were probably to some extent differentiated at the close of the Miocene, the line of demarkation between the two regions was more or less obliterated, at some localities entirely, by the close of the peneplain cycle of erosion, which has been placed at the close of the Pliocene. At that time the Basin Range country in general constituted the uplands whose lowlands were situated, in part at least, in the present Grand Canyon District. At the close of the Pliocene the faulting appears to have been of such a nature that the two districts were again to some extent separated, but it was not until the pronounced faulting which introduced the canyon cycle of erosion that the Basin Range and Plateau provinces, as they are known today, were given, or began to be given, what has since developed into their maximum degree of demarkation.

It may also be noted, as a climatic incident in the history of the region, that a small glacier lived in the large interior valley of San Francisco Mountain, situated on the plateau south of the Grand Canyon, during the canyon cycle of erosion. An attempt has been made to calculate the temperature on the mountain at the time of the glaciation; the problem was approached by three different methods and the results showed reasonable agreements. Without going into the processes of calculation, which are reserved for a future paper, it may be said that the average result gave a temperature of 15° F. less than that of today. This result is in close agreement with determinations made elsewhere, and as it is a fair assumption that the region has experienced only slight changes in elevation since the glacier existed on the mountain, it may be taken as an approximate measure of the difference in temperature in this general region between what was certainly one of the latest and perhaps the last stage of the Glacial period and the present time. It is evident that if conditions were only sufficiently favorable for the existence of a small glacier on the mountain after the region had been elevated possibly as much as 5,000 feet at or

since the beginning of the canyon cycle of erosion they must have been very unfavorable for the existence of any glaciers during the post-peneplain cycle when the region stood nearer sea-level, unless the estimates of temperature during glacial time are much in error. It may be concluded, then, that San Francisco Mountain has experienced only the one period of glaciation which occurred in late Quaternary time.

The Tertiary history of the Grand Canyon District, with geologic dates assigned as given in the preceding pages, may be summarized in conclusion as follows:

I. Period of folding and flexing during the latter half or at the close of the Eocene.

II. Erosion period during the Miocene.

III. First period of faulting at close of the Miocene. A period of extensive faulting. It is correlated with the faulting that gave rise to the Basin Ranges of southern Nevada as tilted block mountains.

IV. The peneplain cycle of erosion during the Pliocene. The Miocene and Pliocene erosion, which are considered as constituting the latter and greater part of the Period of the Great Denudation, closed with the widespread development of a peneplain. This is correlated with the mature topography and local peneplains of the Basin Range country of southern Nevada and of Arizona. Relief produced by previous faulting (III) largely and at some localities entirely obliterated. Widespread volcanic activity, marked by the eruption of basalt, occurred shortly after the development of the peneplain and most probably while the region still stood close to sea-level.

V. The second period of faulting at the close of the Pliocene. Movements probably of less magnitude than those of the first and third periods.

VI. The post-peneplain cycle of erosion during the first part of the Quaternary. Widespread stripping of Permian and Triassic strata and development of a mature topography of low relief, principally on the upper Aubrey limestone, at a horizon ranging from zero to 1,000 feet below the level of the peneplain. Further retreat of the high cliffs on the north and east sides of the district. Land stood at no great height above the sea.

VII. The third period of faulting, with broad regional uplift, during the middle or latter part of the Quaternary. Region raised from 4,000 to 6,000 feet above the position it occupied at the close of the post-peneplain cycle of erosion.

VIII. The canyon cycle of erosion during the latter part of the Quaternary. Marked by the development of a canyon system of drainage of extreme youthfulness. Refreshing of cliff profiles. Erosion otherwise very slight. Colder atmospheric conditions prevailed during part of this cycle, at least, as indicated by the existence of a small glacier on San Francisco Mountain.

Editorial

Are there line fences in science?

In the early days when the untilled prairies of the great American midland were broad and the tillers few, it was the rule to leave wide "turnrows" of virgin sod next the line fences. At a later stage these came to be almost the only virgin ground left, and they lingered here and there as the choicest residues of primitive fertility and native life. Since these in turn passed away, the tillage of each field has pressed hard on its neighbor's ground. It has been somewhat so in the scientific domain. The once neglected turnrows have become the fields that most invite culture. But this has been said before.

Notwithstanding this parallel, one is sometimes prompted to ask if there are indeed line fences in science. Have metes and bounds of ownership been set, at which one's work must stop? May the arbitrator say: To this point you may plow and plant, but no farther? Or is the tillage of the sciences reciprocal like the cropping of the cereals and the legumes? The more they are interplanted, within limits, the better for *both* crops, the Chinese say.

The question is concrete and takes sharp outline only through a concrete case. In citing such a case, matter may thereby get into print that is not in print, nor on the road to print; matter adjudged out of bounds, because it trespassed on others' fields.

It is permissible to cite such a case the more freely because the one in mind came at a time when bounds were shifting, when the chief parties in interest were absent or preoccupied. The case thus takes cover under the latitudinal functions of the important subordinate and the anonymous critic. It is moreover a case of friends among friends; it is not a scrap between hostiles. The case may not be material in itself, though it relates to an important inquiry, and lies at the threshold of an important enterprise. It

would become important—important as a signal—if it were talismanic or were to become talismanic.

The evolution of the Bureau of Mines from a branch of the national Geological Survey is a historical event of a high order of importance in the progress of science as an aid to human welfare. It is worthy of note that the evolution is coincident with a critical stage in the progress of the chief inquiry to which the bureau has set itself, the protection of life against preventable disaster. The imperative nature of this inquiry has been impressed upon the world by the appalling disasters of 1907. That the main source of such disasters lies in the explosibility of coal dust rather than in explosions of pre-existent gases, and in the improper handling of explosives as the exciting agency, had already been recognized by critical investigators and had been set forth measurably in the literature of the subject, but it had not been accepted widely enough to be effective with those in whose hands the remedy rests. The further work to be done to attain practical success lay in more convincing evidence of the sources of disaster, in the discovery of effective preventives and in such education respecting these as is requisite to their effective adoption, a task at once of research, of invention, of demonstration, and of inculcation, in which each factor is imperative to the success of the whole.

When the shock of the disasters of the fall of 1907 awakened intense interest in the problem, the initial steps toward finding a method of forestalling such calamities had already been taken in America, following earlier steps of like nature in England, France, Belgium, and Germany; but as yet these had not reached sufficiently impressive demonstrations of the sources of disaster and were occupied with doubtful devices for prevention. The line of preventive measures which now seems the most promising had, indeed, been suggested many years earlier, but on limited grounds. It had failed to be adequately stimulative; indeed it seems to have fallen into practical oblivion. The American movement thus entered an open and urgent field with little more than the handicap of lesser experience and of a younger and busier community.

With a wise sense of the value of co-operative methods, the

leader of the chief American movement chose for the investigation of the signal disasters in Pennsylvania and West Virginia an expert in explosives, an experienced inspector of mines, and a specialist in rock-gases. These worked co-operatively and yet in measurable independence. Less than two months after the inspection of the chief disasters, the specialist in rock-gases reported progress (February 15, 1908) of which the following is an extract:

SOME SPECIALLY SUGGESTIVE RESULTS

Another line of attack upon the problem which now looks as though it might lead to results of much importance was opened up last Tuesday when I made comparative analyses of the fresh coal, the uncharred dust, and the charred dust from a single room in No. 8 Mine at Monongah. In room No. 3 on the 3d right off the 2d north in Mine No. 8 we found the props heavily plastered with charred dust on the inby sides, while adhering to the outby sides of the same props was a thick deposit of uncharred dust. These dusts were in such quantities that cans were filled with samples of each which were collected with much care. At the same time a third can was filled with fresh coal taken from the rib a few feet away. This was ideal material for a comparative study. My analyses show the following results:

FRESH COAL

Moisture	1.24
Volatile matter	35.28
Fixed carbon	59.88
Ash	3.60
	100.00

UNCHARRED DUST

	First sample	*Second sample*
Moisture	2.30	2.34
Volatile matter	24.13	23.43
Fixed carbon	45.01	45.19
Ash	28.56	29.04
	100.00	100.00

CHARRED DUST

	First sample	*Second sample*
Moisture	1.13	1.20
Volatile matter	24.78	24.36
Fixed carbon	58.11	59.33
Ash	15.98	15.11
	100.00	100.00

An inspection of these analyses shows a striking difference in the percentage of ash. While a slight increase in the percentage of ash necessarily results

from the loss of the volatile matter this accounts for but a small part of the great increase in the ash from these two dusts over that in the original coal. The difference is clearly due to the admixture of finely powdered shale swept up by the explosion. Small fragments of shale were readily recognized in the ash residue after the carbon had all been burned out. A fact which I believe to be of great significance is that *the uncharred dust contains nearly twice as much ash* (*shale dust*) *as the charred dust*. These dusts came from the opposite sides of the same identical props in a room into which the flames penetrated. Both dusts must have been subject to the explosion and yet they are very different in composition, the difference everywhere in the room depending upon which side of the prop the dust was located, the explosion having served as an admirable sorter. Now the explosion did not originate in this room, but advanced into it from the entry, and the outby sides of the props against which the dust was forcibly driven by the explosion are coated with dust containing nearly twice as much shale dust as is contained in the charred dust on the inby exposures of the props. The other and most significant difference is that the dust (on outby exposures) containing *28 per cent of ash and shale* is *not charred* while the dust (on inby exposures) which contains *only 15 per cent of ash and shale* is *charred* and has lost much more of its volatile hydrocarbons.

The differences in the charring of the dust and in the proportion of fine shale in the dust, I believe, are interrelated, one being the result of the other. The explanation, I think, is this: The dust is driven against the outby sides of a prop with much force but not with equal force, the shale particles by reason of their density being driven against it with greater force and hence more likely to stick. The portion which adheres on the outby side of the prop therefore contains more shale dust and less coal dust than an average sample. In the lee of the prop there is a reduced pressure, and an eddying current laps around against the inby side and permits more quiet adhesion. Now the specific gravity of this coal is 1.30 while that of average shale is about 2.60, which is just twice that of the coal. The coal dust is also likely to be finer than the particles of shale. Hence much of the heavier shale particles will be carried on past the post, while the weaker eddying current which touches the lee side will contain a much higher percentage of the lighter coal and less of the heavier shale. This explains the difference in the percentage of ash brought out so strikingly by the analyses.

The high percentage of shale in the dust by diluting the combustible dust and absorbing much of the heat necessary to inflame it has had such a dampening effect upon the combustion that the coal dust which was driven against the props directly was not charred. But in the lee of the props where the proportion of non-inflammable shale has been much reduced and the expulsion of the volatile combustibles is favored by the partial relief of pressure and the slower current, the dust yields up to the flame much more of its inflammable gases and becomes charred or even coked.

. . . . . .

In addition to the theoretical and scientific interest attached to this new idea, I think this line promises much of practical value in the prevention of dust explosions, and these are the most disastrous of the mine explosions. If the presence of a certain proportion of shale dust mixed with the coal dust greatly reduces the explosibility of the latter, and reduces the volume of combustible gases which are fed to the flame so that the dust is not charred, it would seem that the addition of somewhat more pulverized shale would render the dust incapable of propagating an explosion. The force of the explosion itself gathered up 25 per cent of shale dust and if more shale were added artificially to the dust in the entries and rooms an explosion, even if once started, which would be much less likely, might snuff itself out before traveling throughout the whole mine. The addition of shale to the coal dust should be a comparatively simple matter. As soon as wet, by forming mud it should adhere to the coal dust and prevent the latter from becoming stirred up into the air for a long time after it had dried. Perhaps a very effective way to treat the dust would be to use a sort of shale douche made by mixing into the water used in sprinkling a mine a certain quantity of finely ground shale. While sprinkling with water alone does little good after the water has dried up, which takes place rapidly in winter, a shale douche by covering the coal dust with a thin coating of fine shale should keep the dust in a condition unfavorable for an explosion for some time after the water had dried. This being so, stronger ventilation could be used to remove the gas without the increased danger of a dust explosion.

A fuller report embracing further work was submitted later in the year. In the absence of the chief from the Washington office, this had an experience not altogether unknown in official practice. In the wisdom of the vicarious authority then regnant it passed beneath the blue pencils of unknown critics who found, among other things, that its furrows ran over the bounding line of the geo-chemical field and turned up some things thought to lie in the domain of engineers. It is not known that the critics were engineers and so naturally subject to sensitiveness as to the metes and bounds of the engineering field. The internal evidence implies that they were not engineers, at least not engineers acute to see what was latent in the geo-chemist's suggestions. At any rate the suggestions of the rock-gas expert were heroically blue-penciled. Their author, while arguing their legitimacy and their stimulative, directive, and educational value, made no appeal to the men higher up. It is not comfortable or diplomatic to make such an appeal when the merits or the good taste of one's products are in

question, and so, as a compromise, or as a mitigation of the surrender, if you please, the emasculated section that laps from p. 55 over onto p. 56 of *Bulletin 383*, U.S. Geol. Survey, on "Explosive Mine Gases and Dusts with Special Reference to Explosions in the Monongah, Darr and Naomi Coal Mines," is all that found its way to the printer. Whether the intervention of unknown critics between governmental investigators and the public is wholesome or unwholesome no doubt depends on the competency of the criticisms, the spirit in which they are made, and the degree of insistence of the officer in charge as to how far the author must accept or must bow to them. In cases permissible to cite—and this seems to be one—the scientific public may be glad to know in concrete detail how the system works in actual practice where no unfriendly relations are presumed to enter to bias the course of procedure. The blue-penciled matter is as follows, and may be compared with the substitute just cited:

PRACTICAL SUGGESTIONS SPRINGING FROM THESE ANALYSES

Final conclusions can, of course, only be reached after the most complete investigation possible, but meanwhile it is important to make all practical advances in the improvement of conditions on which so many lives depend, and every suggestion springing from the investigation is likely to have some value, both in mine control, and in further investigation. To this end, the suggestions of the foregoing observations in the mines, and in the laboratory, will be frankly stated, subject to modifications as further investigation and practical experience require; particularly as these observations and analyses give rise to a very definite suggestion as to a possible mode of reducing the liability of dusts to explode. This suggestion grows out of the striking difference which the analyses disclose between the charred, uncharred, and fresh coal dusts, with regard to the respective percentages of shale in them, particularly as shown on the opposite sides of the props in the Monongah mine. These differences indicate that the proportion of shale present in the dust exerted a marked influence upon the degree of coking, and the extent to which the dusts participated in the explosions. They suggest that the principle which seems to be involved, might be applied to effectually reduce the danger of a general explosion throughout a mine, if not to render such general explosion practically impossible. Even if a local explosion is inevitable at times from the sudden issue of gas, or from some other unavoidable incident, it is important to prevent the general extension of the explosion throughout the mine. In the cases in hand, this seems to have been a most serious phase of the disasters. If a moderate amount of fine shale mixed with the coal dust

may have such a retarding effect upon the charring of the dust, as it appears to have had in the room studied at Monongah, it would seem that, by an addition of sufficient quantities of finely powdered shale, or earth material of similar kind, to the coal dust, we might reasonably expect that the latter would be rendered essentially non-explosive.

. . . . . .

Whatever may have been the immediate causes which precipitated these terrible disasters, the general, underlying cause of all of them seems to have been an explosive condition of the mine dusts, owing to the drying effect of strong ventilation at this season of the year. The strong ventilating currents were intended to dilute and remove the firedamp before it could accumulate in dangerous quantities, and to furnish good air to the miners. In both of these directions they were effective. But they dried the dusts, and therein seems to lie the source of greatest danger in the bituminous mines of this region. Simple gas explosions without the co-operation of dust could, certainly in the Monongah, and probably also in the Darr and Naomi mines, occur only as very localized explosions of pockets of gas, affecting only a very small portion of the mines. General mine explosions, due to gas alone, would seem impossible with the present ventilating systems of these mines in good working condition. The great extent and destructiveness of these recent explosions seem to have been due almost entirely to the coal dust.

Mutual Relations of Methods of Control

It is obvious that a first condition in the proper control of a coal mine is an effective system of ventilation, for this is the only safe remedy against the dangerous accumulation of methane and other explosive gases which may issue from the coal formation at unexpected times and threaten an explosion. Good ventilation is even more necessary for the health of the miners. It is indispensable. In the mines under investigation it appears to have been wholly adequate, but the investigation seems to show that ventilation itself has its dangers, and that these increase in proportion to the very effectiveness of this necessary measure. During the months in which cold air is forced in large quantities into warm mines, as is inevitable in the on-coming cold season following the summer warmth, the mines, as we have seen, are liable to become excessively dry and subject to dust explosions, even when they are fully protected against all serious gas explosions. Such general dust explosions may start from gas explosions that would, in themselves, be comparatively unimportant, or they may spring from entirely different causes, as defective blasting. The most serious problem, therefore, seems to be the development of practical devices by which the dangers of effective ventilation in the cool season may be reduced to the lowest possible terms. The chief practical suggestion of the foregoing investigation relates to this critical point of forestalling the incidental danger of an adequate system of ventilation which is, in itself, an absolute necessity to good mining conditions.

The chief precaution which has been taken against dust explosions in the past has been to sprinkle the entries with water, but sprinkling the mine with ordinary water is effective only so long as the dust is kept in a moist condition, which is not long in the winter time. This method seems to have been ineffective in these exploded mines because the sprinkling did not reach the various points in the mines until long after the water of the previous wetting had evaporated and the dust become dry. Water, in order to constitute any real safeguard by itself, must be sprayed over all parts of a mine at short intervals. This involves much labor, and, in time, expense. It also has the great disadvantage of weakening the roof in certain mines and increasing the likelihood of rock falls which, after all, cause more fatalities than explosions. Turning exhaust steam into the intake air, while it helps to raise the temperature of the air and supply it with moisture, also favors rock falls, and in addition is said to rot the mine timbers.

A suggestion which has been made is to sprinkle with a solution of calcium chloride instead of pure water. Calcium chloride has such a strong affinity for water that it absorbs moisture rapidly from the air, and a solution of it could never be evaporated dry in ordinary atmospheric air. Dust, wet with a strong solution of calcium chloride should remain damp for a long time, even though the circulating air were in the proper condition to exert a strong drying influence upon the mine. Treated in this way, the dust might be kept so thoroughly dampened that the chances of a dust explosion would be greatly reduced. The expense of using this solution need not be very great, for calcium chloride can be cheaply manufactured. However, with the mine wet with a strong solution of calcium chloride, it is possible that the miners, by constantly coming in contact with it, might suffer both from the rotting of their clothing and possibly an injurious effect upon their health.

Arising from the studies of the dust at Monongah are the suggestions that the explosibility of coal dust may be much reduced by mixing with it finely pulverized shale. One of the most obvious ways to mix this non-combustible matter with the coal dust on the ribs and timbers of a mine is to stir finely ground shale, or similar earthy material, into the water with which the mine is sprinkled. It is clear that means can be devised by which it will be possible to keep shale, mud, or lime constantly stirred up in the water during the operation of sprinkling. When the water dries it must leave behind the mineral matter held in suspension and thus form a coating upon the walls. If this operation be frequently repeated, the amount of non-combustible impurity mixed with, and adherent to, the dust on the ribs must steadily increase and render the coal dust less and less capable of feeding and carrying an explosion flame, so long as the dusts remain mixed.

One of the greatest possible advantages which may be claimed for the use of shale, earth, or lime, in the water, is based upon the property of mud to adhere to that with which it comes in contact, and to hold together, even after

it has become completely dry. By adhering to the particles of fine coal, this dust would be much less readily stirred into the air in everyday mining operations. The mud, clay, shale, or whitewash coating upon the ribs and props must bind the coal dust particles to the coal or timbers with sufficient tenacity to prevent them from being swept up by the ordinary currents of air passing through the entries. Because of greater adhesiveness, mud or soft, clayey shale should be preferable to the more indurated slates, while whitewash has some properties which make it superior to either. Perhaps a mixture of lime and shale, or clay, would prove preferable to either of the constituents used alone.

Since the effects of sprinkling with this shale douche or mixture of earthy material and whitewash last after the water has evaporated, it would not be necessary to sprinkle the entries so often as when water alone is used, for this property of non-combustible shale to diminish the inflammability of the coal dust is not dependent upon the presence of a continuous supply of moisture in the mines. Unlike sprinkling with water alone, if the dust is once made comparatively harmless by the admixture of a very large amount of very fine shale, or similar adhesive mineral matter, it remains so (even though the mine be completely dried out) until an additional amount of coal dust has accumulated, or the dusts in some way become partially separated. Whether the dust be wet or dry becomes less important, though wetness constitutes, of course, an additional safeguard. This manner of treatment implies a certain amount of spraying with water, but a far less amount than the ordinary sprinkling method. Hence the chief dangers of increased rock falls, and other drawbacks of the common water method might be largely escaped.

The treatment of the entry floors is simpler than that of the walls. The pavement may be sprinkled with the same preparation as the ribs and timbers, but it would probably be better to grind the shale to a fine powder outside of the mines, run it underground in the mine cars and spread the dust uniformly over the pavement, throughout the entries. The coal dust on the floor would then either be mixed with, or buried beneath, several times its weight of mineral substance. If sufficient shale be spread along the entries and fairly tight mine cars are used, the shale or earth on the pavement probably would not need to be renewed for a considerable length of time.

Whether shale dust on the entry floors alone, is competent to check a dust explosion once under way, while the fine coal dust, unmixed with shale or whitewash, is present upon the ribs and timbers, can only be told by trial experiment. That an enormous amount of dust and fine particles of coal is swept along the entries during an explosion was strongly brought out by an inspection of the coal ribs in these exploded mines. Very generally throughout these mines, except where the mechanical force of the explosion was greatly reduced, the exposed corners and protuberances of the coal were rounded and often highly polished on exposures facing the source of the explosion, while

nearly always angular and dull on the corresponding exposures facing from the blast. This rounding indicated much abrasion and wear, and resembled somewhat the familiar polishing of bowlders and pebbles by the sand blasts in arid regions. As this smoothing of corners and burnishing of exposed surfaces was all accomplished in the very short length of time which the explosion occupied in traveling through a given section of an entry, the mass of dust and particles of coal carried along by the blast must have been very great. If such a mass of fine, non-combustible shale dust be swept up from the pavement of an entry which has previously been thickly covered with this material, it is possible that the whole explosion might be stopped by this influence alone.

Because the principles of the shale treatment apply to either wet or dry dusts, it would seem that, by this means, the chief danger of over-ventilation during the cold season of the year might be greatly lessened, if not eliminated. With the coal dust thus treated, the gas in the mines could then safely be removed by the vigorous ventilation which is required to remove the firedamp and to supply the miners with fresh air.

The introduction of shale, clay, or whitewash should be free from any injurious effects, either upon the mine or the miners at work. As these substances do not begrime men to anything like the degree that coal dust does, the conditions in the workings should be improved rather than otherwise, from the miners' standpoint. Whitewash, by rapidly absorbing carbon dioxide from the mine air, should have a favorable influence upon the hygienic conditions of a mine. While sprinkling a mine continually with water weakens the roof and increases the number of rock falls, whitewashed walls, by greatly enhancing the illumination of an entry, make it easier to detect dangerous conditions at the roof.

The introduction of pulverized shale, or other earthy material into a mine, thus increasing the quantity of fine dust in the workings, may possibly seem to be increasing one source of danger while reducing another. The experiments of Sir Frederick Abel have shown that certain mixtures of methane and air which passed a naked flame without any symptom of ignition were inflamed when particles of fine, light, non-combustible powder, such as calcined magnesia, were suspended in the gas.[1]

While these gas mixtures were such as could not be exploded by a naked flame they were, nevertheless, not far below the explosive limit. Professor Abel further qualified the statement of his conclusions in this way: "The power of favoring the ignition of mixtures of firedamp and air was not exhibited by some other powders similar in fineness to the latter, but different in structure and density from this and one or two other non-combustible dusts which may be called active; even different samples of magnesia, differing somewhat in likeness from each other, appeared to possess the activity in different degree."

[1] Sir Frederick Abel, *Proc. Roy. Inst.*, X (1882), 88–113.

Only certain dusts, therefore, possess this property which Professor Abel believed to be due to a contact, or catalytic, action upon the gas mixtures, analogous to that manifested by finely divided platinum toward certain gases.

Just how much influence shale dust could exert in this direction has not been determined. It is possible that a mixture of firedamp and air, very close to the lower limit of inflammability, but still not sufficiently rich in methane to be ignited by a flame, might become ignited from the flame when a certain amount of very fine, dry shale dust was stirred into it. But it is probable that only a gas mixture which was very close to the limit of inflammability could become ignited under these conditions. It is also to be remembered that whatever influence of this sort the shale might have, would be possessed, in a far greater degree, by even a very small amount of coal dust in the air. In mines where there is always coal dust present in varying quantities, the possible activity of fine shale in facilitating an explosion should be negligible in comparison to that of the coal dust. Furthermore, the heavier shale, or earthy material, by adhering to the lighter coal dust, tends to keep it out of the air. Finally, the phenomena of typical dust explosions in which the flame, because of the great abundance or excess of combustible matter furnished by the coal dust (even in non-gassy mines), seeks the fresh intake air indicate that these dust explosions are very different from what would be produced by the ignition of mixtures of firedamp and air rendered explosive by the catalytic action of the dust, but, instead, must be largely a matter of the rapid combustion of the readily inflammable hydrocarbons of the dust itself.

Another objection which might be urged is that the shale and coal dusts may become partially separated owing to their difference in specific gravity. Ordinary air currents can pick up light coal dust more easily than denser shale, or clay, particles. As a result, whatever dust might be stirred into the air would be likely to contain a higher proportion of coal than that on the walls or floors. But still there should be much less coal dust in the air, in absolute mass, than if the shale treatment had not been applied, since the mud, because of its adhesive properties, must hold down much fine coal dust which otherwise might easily become floating in the air. However, when an explosion is once started and under headway, it must sweep up nearly all the available dust, coal and shale alike, and hence it would be the character of this mixed dust which would determine the further progress of the explosion.

The foregoing discussion of suggestive preventive measures which were the direct outcome of observational and experimental data have been extended considerably upon theoretical grounds in order to bring out, in a more comprehensive manner, what advantages and disadvantages might be expected to accompany the use of finely pulverized shale, clay, or other earthy material in the mines. The discussion is intended merely to open up, in a preliminary suggestive way, a field for investigation which appears to show some promise of yielding results.

The emasculated substitute for the foregoing discussion that alone found place in *Bulletin 383*, a page and a fraction in extent, seems to have been so far robbed of effective suggestiveness that it did not call forth even a mention by the author of the historical statement of investigations bearing on the use of stone dust as a deterrent in coal dust explosions given the public in *Bulletin 425* recently issued under the same auspices as *Bulletin 383*, though the unemasculated portions of the latter found suitable recognition, as did also and naturally the important advances made in 1908 and 1909 in France, England, and other European countries in this promising line of preventive endeavor, stimulated apparently, in part at least, by the American disasters.

It is of minor consequence that the bureau thus loses a part of its own legitimate prestige in the new movement and falls into line behind rather than abreast of its European coworkers, for such relative position is mainly a matter of national pride, and this is no doubt a form of vanity, however stimulative and wholesome it may be; but it is not permissible to dismiss so lightly the more vital fact that an aid toward that laborious education which is prerequisite to a final practical success was thrown away by cutting out or cutting down to an ineffectual minimum these suggestions that sprang from one of the main lines of approach attempted, even though the suggestions might be thought to overlap ground lying more directly in the path of some other line of approach. The prerequisite educational work is at once scientific, technical, practical, and popular, and will inevitably be slow because of the human inertia to be overcome. It involves the growth of scientific opinion, usually cautious and hesitant, the growth of public opinion, usually inert and sluggish, the working assent of laborers on whom new restraints must be laid, the concurrence of managers on whom new cares are to be thrown, the co-operation of owners on whom new expenses are to be imposed, the enlightenment of legislators of whom new enactments are to be required, and the inspiration of public officials on whom new duties are to be placed. If the psychological moment for such education in any of its phases is at hand, by reason of the shock of appalling

disasters, is it wise to question too closely the nativity or the caste of the schoolmaster? May he not, after all, have rights on other than his native sod and have proper functions outside the caste limits to which certain ancestral conventions might be disposed to confine him?

T. C. C.

Index to Volume XVIII

PAGE

Adams, Frank D. An Experimental Investigation into the Action of Differential Pressure on Certain Minerals and Rocks, Employing the Process Suggested by Professor Kick 489

———. The Laurentian System in Eastern Canada. Review by E. R. L. 287

Aftonian Sands and Gravels in Western Iowa. By B. Shimek. Review by T. C. C. 294

Age of the Earth and the Saltness of the Sea, The. By H. S. Shelton 190

Aguilera, José G. Catalogo de los temblores (Macroseismos) sentidos en la Republica Mexicana durante los años de 1904 à 1908. Review by W. H. H. 194

Alkaline Rocks, Origin of the. By Reginald A. Daly. Author's Abstract 575

Amphibian Footprints from the Mississippian of Virginia. By E. B. Branson 356

Analcite Basal from Rathjordan, Co. Limerick, On an. By G. T. Prior. Review by Clarence W. Russell 481

Analyses of Rocks and Minerals from the Laboratory of the U.S.G.S. By F. W. Clarke. Review by Charles J. Hares 573

Analysis of Silicate and Carbonate Rocks, The. By W. F. Hillebrand. Review by Albert D. Brokaw 478

Anthracolithic or Upper Paleozoic Rocks of Kansas and Related Regions, The. By Charles S. Prosser 125

Appalachian Folds of Central Pennsylvania, The. By Rollin T. Chamberlin 228

Austin, Leonard S. The Metallurgy of the Common Metals, Gold, Silver, Iron, Copper, Lead, and Zinc. Review by W. H. E. . . . 198

Ball, Sydney H., and Millard K. Shaler. A Central African Glacier of Triassic Age 681

Baraboo Quartzite Range, Wisconsin, The Secondary Structures of the Eastern Part of the. By Edward Steidtman 259

Barbier, Ph. Sur un caractère chimique différentiel des orthoses et des microclines. Review by F. C. Calkins 476

Basische Eruptivgesteine aus den Kitzbüchler Alpen. By Albrecht Spitz. Review by Albert Johannsen 580

Bassler, Ray S. The Cement Resources of Virginia, West of the Blue Ridge. Review by R. T. C. 296

Bastin, Edson S. Origin of the Pegmatites of Maine 297

PAGE

Berry, Edward W. The Evidence of the Flora Regarding the Age of the Raritan Formation 252
Böse, Emilio A. Villafaña y Garcia y Garcia, El temblor del 14 de abril de 1907. Review by W. H. H. 194
———. Los temblores de Zanatepec, Oaxaca, a fines de septiembre de 1902. Review by W. H. H. 194
Bowen, Norman L. Diabase and Granophyre of the Gowganda Lake Mining District, Ontario 658
Branner, J. C. Earthquakes in Brazil 327
Branson, E. B. Amphibian Footprints from the Mississippian of Virginia 356
Bretz, J. Harlen. Glacial Lakes of Puget Sound 448
Brewster, Edwin Tenney. Life and Letters of Josiah Dwight Whitney. Review by R. T. C. 566
British Columbia, a Portion of the Main Coast of, and Adjacent Islands in the New Westminster and Nanaimo Districts, Preliminary Report on. By O. E. Leroy. Review by E. R. L. . . . 287
Brokaw, Albert D. The Solution of Gold in the Surface Alterations of Ore Bodies 321
Buckman, S. S. Yorkshire Type Ammonites. Review by S. W. . 390
Buehler, H. A. The Lime and Cement Resources of Missouri. Review by E. R. L. 287
Bullfrog District, Nevada, Geology and Ore Deposits of the. By F. L. Ransome, W. H. Emmons, and G. H. Garrey. Review by Albert D. Brokaw 482
Butler, Bert S., and Ralph S. Tarr. The Yakutat Bay Region, Alaska. Review by E. R. L. 571

Cairnes, D. D. Report on a Portion of Conrad and Whitehorse Mining Districts, Yukon. Review by E. R. L. 286
California Earthquake of April 18, 1906, The. By A. C. Lawson and Others. Review by W. H. H. 288
California, The Geologic Record of. By James Perrin Smith . . 216
Camsell, Charles. Preliminary Report on a Part of the Similkameen District, British Columbia. Review by E. R. L. 286
Cape Colony, An Introduction to the Geology of. By A. W. Rogers and A. L. DuToit. Review by R. T. C. 391
Capps, Stephen R., Jr. Glaciation on the North Side of the Wrangell Mountains, Alaska 33
———. Rock Glaciers in Alaska 359
Carrizo Mountain and Vicinity, San Diego County, Cal., Notes on the Geology of. By Walter C. Mendenhall 336
Cenozoic through Its Mammalian Life, Correlation of the. By Henry Fairfield Osborn 201

PAGE

Chamberlin, Rollin T. The Appalachian Folds of Central Pennsylvania 228
———. Older Drifts in the St. Croix Region 542
Chamberlin, T. C. and R. T. Certain Valley Configurations in Low Latitudes 117
Chamberlin, Thomas C., and Rollin D. Salisbury. College Geology. Review by R. T. C. 103
Chemical Compositions of Igneous Rock Types, Average. By Reginald A. Daly. Author's Abstract 574
Christensen, Adolf, et Georg Ziemendorff. Les tremblements de terre ressentis pendant l'année 1905. Review by W. H. H. . . . 197
Clarke, F. W. Analyses of Rocks and Minerals from the Laboratory of the U.S.G.S. Review by Charles J. Hares 573
Clay Working Industry in the United States, History of the. By Heinrich Ries and Henry Leighton. Review by R. T. C. . . . 392
Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia. By D. B. Downing. Review by E. R. L. 572
Collecting Area of the Waters of the Hot Springs, Hot Springs, Ark., The. By A. H. Purdue 279
College Geology. By Thomas C. Chamberlin and Rollin D. Salisbury. Review by R. T. C. 103
Collins, W. H. Report on the Region Lying North of Lake Superior between the Pic and Nipigon Rivers. Review by E. R. L. . . . 572
Colorado Geological Survey, First Report. By R. D. George and Others. Review by E. R. L. 575
Conrad and Whitehorse Mining Districts, Yukon, Report on a Portion of. By D. D. Cairnes. Review by E. R. L. 286
Cretaceous-Eocene Contact. By Eugene Allen Smith 430
Crystalline Structure and Chemical Constitution. By A. E. H. Tutton. Review by Albert D. Brokaw 582
Crystals in Light Parallel to an Optic Axis, On the Behavior of. By C. Travis. Review by Albert Johannsen 482

Dale, T. Nelson. The Granites of Vermont. Review by Charles J. Hares 573
Daly, Reginald A. Average Chemical Compositions of Igneous Rock Types. Author's Abstract 574
———. Origin of the Alkaline Rocks. Author's Abstract . . 575
Dannenburg, von. Geologie der Steinkohlenlager. Review by R. T. C. 100
Davis, William Morris. Geographical Essays. Review by R. T. C. 296
Denison University, Bulletin of the Scientific Laboratories of. Vol. XIV. Review by R. T. C. 102
Devonian of Ohio, The Middle. By Clinton R. Stauffer. Review by C. S. P. 474

PAGE

Diabase and Granophyre of the Gowganda Lake District, Ontario. By Norman L. Bowen 658

Diabase of the Cobalt District, Ontario. By Reginald E. Hore . . 271

Diamantführenden Gesteine Südafrikas, Die. Ihr Abbau und ihre Aufbereitung. By Dr. Percy A. Wagner. Review by R. T. C. . 295

Diller, J. S. Geology of the Taylorsville Region, California. Review by E. R. L. 286

Dissorophus Cope. By S. W. Williston 526

Distribution and Signification of Deviations from the Normal Order of Crystallization, also the Distribution and Significance of Micropegmatite in Granites, as Illustrated by the Granites of the North of Scotland. By William Mackie. Review by Albert Johannsen 576

Downing, D. B. The Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia. Review by E. R. L. . . . 572

Drehbarer Compensator für Mikroskop. By W. Nikitin. Review by W. T. Schaller 578

Duparc, Louis. Recherches géologiques et pétrographiques sur l'Oural du Nord. Pt. III. Review by F. C. Calkins . . . 477

DuToit, A. L., and A. W. Rogers. An Introduction to the Geology of Cape Colony. Review by R. T. C. 391

Eakin, Henry M. The Influence of the Earth's Rotation upon the Lateral Erosion of Streams 435

Earthquakes in Brazil. By J. C. Branner 327

Earthquakes—Macroseisms—Felt in the Mexican Republic during the Years 1904–8, Catalogue of the. By José G. Aguilera. Review by W. H. H. 194

Earthquake of April 14, 1907. By Emilio Böse. Review by W. H. H. 194

Earthquakes of Zantepec, Oaxaca, at the End of September in 1902. By Emilio Böse. Review by W. H. H. 194

Editorial. By T. C. C. 468, 764

Editorial. By G. K. G. 675

Emmons, W. H., Frederick Leslie Ransome, and G. H. Garrey. The Geology and Ore Deposits of Goldfield, Nevada. Review by E. R. L. 676

———. Geology and Ore Deposits of the Bullfrog District, Nevada. Review by Albert D. Brokaw 482

Experimental Investigation into the Action of Differential Pressure on Certain Minerals and Rocks, Employing the Process Suggested by Professor Kick, An. By Frank D. Adams 489

Experimentaluntersuchungen über die Ausscheidungsfolge von Silikaten bei zwei und drei Componenten. By R. Freis. Review by E. S. 103

PAGE

Finlay, George I. The Calculation of the Norm in Igneous Rocks . 58

Finlayson, A. M. Petrology and Structure of the Pyritic Field of Huelva, Spain. Review by Albert D. Brokaw 477

Freis, R. Experimentaluntersuchungen über Ausscheidungsfolge von Silikaten bei zwei und drei Componenten. Review by E. S. . 103

Gardner, James H. The Puerco and Torrejon Formations of the Nacimiento Group 702

Garrey, G. H., Frederick Leslie Ransome, and W. H. Emmons. The Geology and Ore Deposits of Goldfield, Nevada. Review by E. R. L. 676

———. Geology and Ore Deposits of the Bullfrog District, Nevada. Review by Albert D. Brokaw 482

Genesis of Loess a Problem in Plant Ecology, The. By B. Shimek. Review by T. C. C. 294

Geographical Essays. By William Morris Davis. Review by R. T. C. 296

Geologie der Steinkohlenlager. By von Dannenburg. Review by R. T. C. 100

George, R. D., and Others. Colorado Geological Survey, First Report. Review by E. R. Lloyd 575

Glacial Deposits, Comparison of North American and European. By Frank Leverett. Review by T. C. C. 470

Glacial Lakes of Puget Sound. By J. Harlen Bretz 448

Glacial Lake Missoula, The. By J. T. Pardee 376

Glacial Origin of Huronian Rocks of Nipissing, Ontario, On the. By Reginald E. Hore 459

Glaciation on the North Side of the Wrangell Mountains, Alaska. By Stephen R. Capps, Jr. 33

Glacier of Triassic Age, A Central African. By Sydney H. Ball and Millard K. Shaler 681

Goldfield, Nevada, The Geology and Ore Deposits of. By Frederick Leslie Ransome, W. H. Emmons, and G. H. Garrey. Review by E. R. L. 676

Golfier, J. Recherche des paramètres qui caractérisent les types classiques de roches éruptives. Review by F. C. Calkins . . 477

Grand Canyon, Arizona, Contributions to the Geology of the. Geology of the Shinumo Area. By L. F. Noble. Reviews by Albert D. Brokaw 481, 579

Grand Canyon District, Arizona, A New Erosion Cycle in the. By H. H. Robinson 742

Granites of Vermont, The. By T. Nelson Dale. Review by Charles J. Hares 573

Gratacap, L. P. Geology of the City of New York. Review by R. T. C. 102

Grout, Frank F. Contribution to the Petrography of the Keweenawan 633

PAGE

Halbsphäroid zur graphischen Lösung bei Anwendung der Universalmethode. By W. Nikitin. Review by W. T. Schaller . . 578
Halle, G. Neuer Hand-Demonstrationsapparat für alle Erscheinungen der Doppelbrechung im Kalkspat. Review by W. T. Schaller . 576
Handbook for Field Geologists. By C. W. Hayes. Review by R. T. C. 99
Hayes, C. W. Handbook for Field Geologists. Review by R. T. C. 99
Hillebrand, W. F. The Analysis of Silicate and Carbonate Rocks. Review by Albert D. Brokaw 478
Hopkins, Cyril G. Soil Fertility and Permanent Agriculture. Review by J. Paul Goode 565
Hore, Reginald E. Diabase of the Cobalt District, Ontario . . 271
———. On the Glacial Origin of Huronian Rocks of Nipissing, Ontario 459
Huelva, Spain, Petrology and Structure of the Pyritic Field of. By A. M. Finlayson. Review by Albert D. Brokaw . . . 477
Humboldt County, Nevada, Notes on Some Mining Districts in. By F. L. Ransome. Review by Charles J. Hares 579

Influence of the Earth's Rotation upon the Lateral Erosion of Streams, The. By Henry M. Eakin 435
Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island. By G. F. Loughlin. Review by Albert Johannsen 480
Iowa Geological Survey, Vol. XIX. Review by R. T. C. . . . 568

Johannsen, Albert. Some Simple Improvements for a Petrographical Microscope. Review by Albert D. Brokaw 479
Johnson, Douglas Wilson, and William Gardner Reed, Jr. The Form of Nantasket Beach 162
Joly, J. Radioactivity and Geology. An Account of the Influence of Radioactive Energy on Terrestrial History. Review by R. T. C. 568

Kansas, University Geological Survey of. Vol. IX. Review by G. H. G. 290
Keweenawan, Contribution to the Petrography of the. By Frank F. Grout 633
Knowlton, F. H. Succession and Range of Mesozoic and Tertiary Floras 105

Lacroix, A. Sur l'existence à la Côte d'Ivoire d'une série pétrographique comparable à celle de la charnockite. Review by F. C. Calkins 479
Lambe, Lawrence M. The Vertebrata of the Oligocene of the Cypress Hills, Saskatchewan. Review by E. R. L. 677
Lane, A. C. Notes on the Geological Section of Michigan. II. From the St. Peter Sandstone Up 393
Larkin, Pierce. The Occurrence of a Sauropod Dinosaur in the Trinity Cretaceous of Oklahoma 93

PAGE

Laurentian System in Eastern Canada, The By F. Dawson Adams. Review by E. R. L. 287

Lawson, A. C., and Others. The California Earthquake of April 18, 1906. Review by W. H. H. 288

Leighton, Henry, and Heinrich Ries. History of the Clay Working Industry in the United States. Review by R. T. C. 392

Leroy, O. E. Preliminary Report on a Portion of the Main Coast of British Columbia and Adjacent Islands in the New Westminster and Nanaimo Districts. Review by E. R. L. 287

Leverett, Frank. Comparison of North American and European Glacial Deposits. Review by T. C. C. 470

Leiss, C. Mikroskop mit gemeinsamer Nicoldrehung in vereinfachter Form. Review by W. T. Schaller 576

Life and Letters of Josiah Dwight Whitney. By Edwin Tenney Brewster. Review by R. T. C. 566

Lime and Cement Resources of Missouri, The. By H. A. Buehler. Review by E. R. L. 287

Loess of the Paha and River-Ridge, The. By B. Shimek. Review by T. C. C. 294

Loughlin, G. F. Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island. Review by Albert Johannsen 480

Mackie, William. The Distribution and Significance of Deviations from the Normal Order of Crystallization, also the Distribution and Significance of Micropegmatite in Granites, as Illustrated by the Granites of the North of Scotland. Review by Albert Johannsen 576

Mainka, C. Eine neue seismische Untersuchungsplatte. Review by W. H. H. 197

Marbut, C. F. Geology of Morgan County, Missouri. Review by E. R. L. 199

Martonne, Emanuel de. Traité de géographie physique. Review by F. L. 387

McConnell, R. G. The Whitehorse Copper Belt, Yukon Territory. Review by E. R. L. 570

Mendenhall, Walter C. Notes on the Geology of Carrizo Mountain and Vicinity, San Diego County, Cal. 336

Mesozoic and Tertiary Floras, Succession and Range of. By F. H. Knowlton 105

Metallurgy of the Common Metals, Gold, Silver, Iron, Copper, Lead, and Zinc, The. By Leonard S. Austin. Review by W. H. E. 198

Michigan, Notes on the Geological Section of. II. From the St. Peter Sandstone Up. By A. C. Lane 393

PAGE

Mikroskop mit gemeinsamer Nicoldrehung in vereinfachter Form. By C. Leiss. Review by W. T. Schaller 576
Mindanao and the Sulu Archipelago, A Geological Reconnaissance of the Island of. By Warrren D. Smith. Review by R. T. C. 101
Mineralogy, Crystallography, and Blowpipe Analysis from a Practical Standpoint, Elements of. By Alfred J. Moses and Charles Lathrop Parsons. Review by W. H. E. 199
Missouri Bureau of Geology and Mines, Biennial Report of the State Geologist. Review by E. R. L. 200
Missouri, Geology of Morgan County. By C. F. Marbut. Review by E. R. L. 199
Missouri, The Geology of Pike County. By R. R. Rowley. Review by E. R. L. 200
Moses, Alfred J., and Charles Lathrop Parsons. Elements of Mineralogy, Crystallography, and Blowpipe Analysis from a Practical Standpoint. Review by W. H. E. 199

Nantasket Beach, The Form of. By Douglas Wilson Johnson and William Gardner Reed, Jr. 162
Neuer Hand-Demonstrationsapparat für alle Erscheinungen der Doppelbrechung im Kalkspat. By G. Halle. Review by W. T. Schaller 576
New South Wales, Epitome of the Geology of. By E. F. Pittman. Review by R. T. C. 566
New York, Geology of the City of. By L. P. Gratacap. Review by R. T. C. 102
Nikitin, W. Drehbarer Compensator für Mikroskop. Review by W. T. Schaller 578
———. Halbsphäroid zur graphischen Lösung bei Anwendung der Universalmethode. Review by W. T. Schaller 578
Nitrate Deposits of Chile, The. By R. A. F. Penrose, Jr. . . . 1
Noble, L. F. Contributions to the Geology of the Grand Canyon, Arizona. The Geology of the Shinumo Area. Reviews by Albert D. Brokaw 481, 579
Norm in Igneous Rocks, The Calculation of the. By George I. Finlay 58
Norsk geologisk tidsskrift (Norwegian Geological Magazine), Vol. I. Review by Hans Reusch 392

Ocular for Use with the Petrographic Microscope, A New. By Fred Eugene Wright. Review by Albert Johannsen 483
Older Drifts in the St. Croix Region. By Rollin T. Chamberlin . 542
Oligocene of the Cypress Hills, Saskatchewan, The Vetebrata of the. By Lawrence M. Lambe. Review by E. R. L. 677

PAGE

Omori, F. Report of the Observation of Pulsatory Oscillations in Japan (1st paper). Review by W. H. H. 198

Ontario, Eighteenth Annual Report of the Bureau of Mines. Review by E. R. L. 570

Ontario, Report on a Portion of the Algoma and Thunder Bay Districts. By W. J. Wilson, and on the Region Lying North of Lake Superior between the Pic and Nipigon Rivers. By W. H. Collins. Review by E. R. L. 572

Orthoses et des microclines, Sur un caractère chimique différentiel des. By Ph. Barbier. Review by F. C. Calkins 476

Osborn, Henry Fairfield. Correlation of the Cenozoic through Its Mammalian Life 201

Oscillations in Japan, Report of the Observation of Pulsatory. By F. Omori. Review by W. H. H. 198

Pardee, J. T. The Glacial Lake Missoula 376

Parsons, A. L. Ein neues Sklerometer. Review by W. T. Schaller . 579

Parsons, Charles Lathrop, and Alfred J. Moses. Elements of Mineralogy, Crystallography, and Blowpipe Analysis from a Practical Standpoint. Review by W. H. E. 199

Peculiar Cleavage Structure Resembling Stretched Pebbles, near Ellijay, Georgia, On a. By W. C. Phalen 554

Pegmatites of Maine, Origin of the. By Edson S. Bastin 297

Penhallow, D. P. Report on Tertiary Plants of British Columbia. Review by E. R. L. 677

Pennsylvania, Report of Topographic and Geologic Survey Commission of. Review by E. R. L. 200

Penrose, R. A. F., Jr. The Nitrate Deposits of Chile 1

Permian Reptiles: Rhachitomous Vertebrae, New. By S. W. Williston 585

Petrographical Microscope, Some Simple Improvements for a. By Albert Johannsen. Review by Albert D. Brokaw 479

Petrographic Microscope, A New. By Fred Eugene Wright. Review by Albert Johannsen 483

Petrological Abstracts and Reviews 476, 573

Phalen, W. C. On a Peculiar Cleavage Structure Resembling Stretched Pebbles, near Ellijay, Georgia 554

Physiography of the Bishop Conglomerate, Southwestern Wyoming, The. By John Lyon Rich 601

Pikrite des sächsischen Vogtlandes, Die. By Alfred Uhlemann. Review by Albert Johannsen 581

Pittman, E. F. Epitome of the Geology of New South Wales. Review by R. T. C. 566

Platecarpus, A Mounted Skeleton of. By S. W. Williston . . . 537

PAGE

Prior, G. T. On an Analcite Basalt from Rathjordan, Co. Limerick. Review by Clarence W. Russell 481
Prosser, Charles S. The Anthracolithic or Upper Paleozoic Rocks of Kansas and Related Regions 125
Puerco and Torrejon Formations of the Nacimiento Group, The. By James H. Gardner 702
Purdue, A. H. The Collecting Area of the Waters of the Hot Springs, Hot Springs, Ark. 279

Radioactivity and Geology. An Account of the Influence of Radioactive Energy on Terrestrial History. By J. Joly. Review by R. T. C. . 568
Ransome, F. L. Notes on Some Mining Districts in Humboldt County, Nevada. Review by Charles J. Hares 579
Ransome, F. L., W. H. Emmons, and G. H. Garrey. Geology and Ore Deposits of the Bullfrog District, Nevada. Review by Albert D. Brokaw 482
———. The Geology and Ore Deposits of Goldfield, Nevada. Review by E. R. L. 676
Raritan Formation, The Evidence of the Flora Regarding the Age of the. By Edward W. Berry 252
Recent Publications 484, 678
Recherche des paramètres qui caractérisent les types classiques de roches éruptives. By J. Golfier. Review by F. C. Calkins . 477
Recherches géologiques et pétrographiques sur l'Oural du Nord. By Louis Duparc. Review by F. C. Calkins 477
Reed, William Gardner, Jr., and Douglas Wilson Johnson. The Form of Nantasket Beach 162
Reid, Harry Fielding. Seismological Notes. Review by W. H. H. . 195
Reviews 99, 194, 286, 387, 470, 565, 676
Rich, John Lyon. The Physiography of the Bishop Conglomerate, Southwestern Wyoming 601
Ries, Heinrich, and Henry Leighton. History of the Clay Working Industry in the United States. Review by R. T. C. 392
Robinson, H. H. A New Erosion Cycle in the Grand Canyon District, Arizona 742
Rock Glaciers in Alaska. By Stephen R. Capps, Jr. 359
"Rock Glaciers" or Chrystocrenes. By J. B. Tyrrell 549
Rogers, A. W., and A. L. DuToit. An Introduction to the Geology of Cape Colony. Review by R. T. C. 391
Rowley, R. R. The Geology of Pike County, Missouri. Review by E. R. L. 200

Salisbury, Rollin D., and Thomas C. Chamberlin. College Geology. Review by R. T. C. 103

PAGE

Sauropod Dinosaur in the Trinity Cretaceous of Oklahoma, The Occurrence of a. By Pierce Larkin 93

Seismischen Strörungen, Katalog der im Jahre 1905 registrierten. By Siegmund Szirtes. Review by W. H. H. 197

Seismische Untersuchungsplatte, Eine neue. By C. Mainka. Review by W. H. H. 197

Seismogramme des japanischen Erdbebens am 21. Januar 1906. By Siegmund Szirtes. Review by W. H. H. 197

Seismological Notes. By Harry Fielding Reid. Review by W. H. H. 195

Shaler, Millard K., and Sydney H. Ball. A Central African Glacier of Triassic Age 681

Shelton, H. S. The Age of the Earth and the Saltness of the Sea . 190

Shimek, B. The Genesis of Loess a Problem in Plant Ecology. Review by T. C. C. 294

———. The Loess of the Paha and River-Ridge. Review by T. C. C. 294

———. Aftonian Sands and Gravels in Western Iowa. Review by T. C. C. 294

Similkameen District, British Columbia, Preliminary Report on a Part of the. By Charles Camsell. Review by E. R. L. . . 286

Sklerometer, Ein neues. By A. L. Parsons. Review by W. T. Schaller 579

Smith, Eugene Allen. Cretaceous-Eocene Contact 430

Smith, James Perrin. The Geologic Record of California . . . 216

Smith, Warren D. A Geological Reconnaissance of the Island of Mindanao and the Sulu Archipelago. Review by R. T. C. . . . 101

Soil Fertility and Permanent Agriculture. By Cyril G. Hopkins. Review by J. Paul Goode 565

Solution of Gold in the Surface Alterations of Ore Bodies, The. By Albert D. Brokaw 321

Spitz, Albrecht. Basische Eruptivgesteine aus den Kitzbüchler Alpen. Review by Albert Johannsen 580

Stauffer, Clinton R. The Middle Devonian of Ohio. Review by C. S. P. 474

Steidtman, Edward. The Secondary Structures of the Eastern Part of the Baraboo Quartzite Range, Wisconsin 259

Sur l'existence à la Côte d'Ivoire d'une série pétrographique comparable à celle de la charnockite. By A. Lacroix. Review by F. C. Calkins 479

Szirtes, Siegmund. Katalog der im Jahre 1905 registrierten seismischen Störungen. Review by W. H. H. 197

———. Seismogramme des japanischen Erdbebens am 21. Januar 1906. Review by W. H. H. 197

———. Unifilares Horizontalpendel. Review by W. H. H. . . . 197

Tarr, Ralph S., and Bert S. Butler. The Yakutat Bay Region, Alaska. Review by E. R. L. 571

PAGE

Taylorsville Region, California, Geology of the. By J. S. Diller. Review by E. R. L. 286
Tertiary Plants of British Columbia, Report on. By D. P. Penhallow. Review by E. R. L. 677
Traité de géographie physique. By Emanuel de Martonne. Review by F. L. 387
Travis, C. On the Behavior of Crystals in Light Parallel to an Optic Axis. Review by Albert Johannsen 482
Tremblements de terre ressentis pendant l'année 1905, Les. By Adolf Christensen et Georg Ziemendorff. Review by W. H. H. . . 197
Tutton, A. E. H. Crystalline Structure and Chemical Constitution. Review by Albert D. Brokaw 582
Tyrrell, J. B. "Rock Glaciers" or Chrystocrenes 549

Uhlemann, Alfred. Die Pikrite des sächsischen Vogtlandes. Review by Albert Johannsen 581
Unifilares Horizontalpendel. By Siegmund Szirtes. Review by W. H. H. 197

Valley Configurations in Low Latitudes, Certain. By T. C. Chamberlin and R. T. Chamberlin 117
Virginia, West of the Blue Ridge, The Cement Resources of. By Ray S. Bassler. Review by R. T. C. 296

Wagner, Dr. Percy A. Die Diamantführenden Gesteine Südafrikas. Review by R. T. C. 295
Whitehorse Copper Belt, Yukon Territory, The. By R. G. McConnell. Review by E. R. L. 570
Williston, S. W. Dissorophus Cope 526
———. A Mounted Skeleton of Platecarpus 537
———. New Permian Reptiles: Rhachitomous Vertebrae . . . 585
Wilson, W. J. Report on a Portion of the Algoma and Thunder Bay Districts, Ontario. Review by E. R. L. 572
Wright, Fred Eugene. A New Ocular for Use with the Petrographic Microscope. Review by Albert Johannsen 483
———. A New Petrographic Microscope. Review by Albert Johannsen 483

Yakutat Bay Region, Alaska, The. By Ralph S. Tarr and Bert S. Butler. Review by E. R. L. 571
Yorkshire Type Ammonites. Edited by S. S. Buckman. Review by S. W. 390

Ziemendorff, Georg. See Adolf Christensen . . . . . .